STRATEGIC POSITIONING OF UNITED STATES AIR FORCE CIVIL ENGINEER CONTINGENCY EQUIPMENT WITHIN THE SUPPLY CHAIN

THESIS

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Abstract

The consolidation and forward positioning of critical inventories often provides substantial benefits over a geographically dispersed posture. Such benefits include, but are not limited to: increased inventory visibility, reduced transportation costs, and fewer manpower requirements. Presently, the United States Air Force (USAF) Civil Engineer (CE) community maintains a disseminated posture of equipment Unit Type Codes (UTCs), which regularly experiences inconsistencies in handling, tracking, and capability reporting. Provided the aforementioned discrepancies, this research effort examines several aspects surrounding the decision to potentially centralize critical CE inventories to either one or two locations. Specifically, the areas of cost, risk, and manpower are scrutinized to facilitate an objective decision by USAF CE senior leaders on whether or not to pursue an alternative equipment posture. Three scholarly articles are presented covering each area of interest and data supported recommendations are provided. The research offers insight concerning the decision of inventory consolidation as well as available methods to facilitate such a determination.

To my beautiful wife

Acknowledgments

I would like to thank my thesis advisor, Lt Col Tay Johannes. His vision, leadership, support, and advice provided the foundation for a successful thesis effort. I would also like to express my appreciation to Lt Col Joseph B. Skipper, Dr. Edward White, and Dr. James Chrissis, who offered their time and expertise to serve on my committee. Without their support and insight, this research effort would not have been possible. I also owe a debt of gratitude to my research sponsors: Lt Col George Petty, Maj Gregory Osbourne, and Mr. Larry Lomax, from the Air Force Civil Engineer Center for both the support and latitude provided to me in this endeavor. Without their continual efforts this thesis would not have come to fruition. Lastly, I am thankful to my incredible wife. I am forever indebted to her for the amount of patience and love she showed me during this process.

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STRATEGIC POSITIONING OF UNITED STATES AIR FORCE CIVIL ENGINEER CONTINGENCY EQUIPMENT WITHIN THE SUPPLY CHAIN

I. Introduction

This chapter establishes the research topic by concisely presenting background information and the problem statement. Additionally, the research approach is detailed to include research objectives, an outline of succeeding thesis chapters is discussed.

Background

In a dynamic world full of uncertain threats, the United States military is constantly required to evolve and enhance its capabilities to effectively defend the nation. One of the military capabilities requiring continuous improvement to ensure pursuit of American interests is that of focused logistics. The Chairman of the Joint Chiefs of Staff (CJCS) defines focused logistics as "the ability to provide the joint force the right personnel, equipment, and supplies in the right place, at the right time, and in the right quantity, across the full range of military operations" (CJCS, 2000).

The United States Air Force (USAF) has made significant advancements to successfully execute focused logistics; recent reorganization of force structure and equipment bundling allows senior officials to tailor units to meet the specific requirements for any range of contingency operations that may arise (Galway, Amouzegar, Hillestad, and Snyder, 2002; Snyder, Mills, Carrillo and Resnick; 2006). Unit Type Codes (UTCs) act as the building blocks for constructing these units; each UTC representing a skill or capability specific to personnel or equipment (DAF, 2011; DAF, 2006; DAF, 2013). For instance, a personnel UTC might consist of an engineering assistant (EA) team whose skills are utilized to facilitate base layout and construction activities; whereas, an equipment UTC might consist of surveying tools that allow the EA team to successfully complete its required tasks. While the example presented is representative of a typical USAF civil engineer (CE) UTC, the concept is employed across a wide range of functional areas from aircraft maintenance to security forces. The development of scalable, modular personnel and equipment packages certainly facilitates the focused logistics operational concept; but, as previously mentioned, such capabilities require continuous improvement.

In addition to the personnel and equipment bundling method enhancements, substantial efforts have been made to investigate equipment posture. Recent studies conducted for the USAF security forces and medical fields indicate the consolidation of equipment UTCs may yield benefits with respect to process efficiencies, inventory visibility, and manpower savings (Overstreet, 2004; Skipper, Bell, Cunningham, and Mattioda, 2010). Similar studies, focused on forward placement of equipment, suggest benefits associated with decreased delivery time and transportation cost (McNulty, 2003; Amouzegar, Tripp, & Galway, 2004; Ghanmi and Shaw, 2008; McCormick, 2009; Skipper *et al.*, 2010). Such findings certainly impact the capability of focused logistics; by pursuing consolidation and forward placement, forces are provided with a more efficient and responsive supply structure that further ensures “right time” delivery by reducing equipment closure times.

Problem Statement

In October of 2012, the Air Force Civil Engineer Center (AFCEC) released a study concerning the current posture of equipment UTCs maintained by the CE community. The study cites inconsistencies in handling, tracking, and capability reporting due to the geographical dispersion of equipment; in addition, system redundancies are also evident which create unneeded waste (AFCEC, 2012). As a result of the current system inefficiencies and previous findings concerning consolidation and forward placement of inventory, the CE community began to review alternative options for equipment UTC posture within the continental United States (CONUS). The review established three courses of action (COAs):

1. Maintain current dispersed posture
2. Establish one CONUS holding location near a Port of Embarkation (POE)
3. Establish two CONUS holding locations, one on the west and east coast near a POE

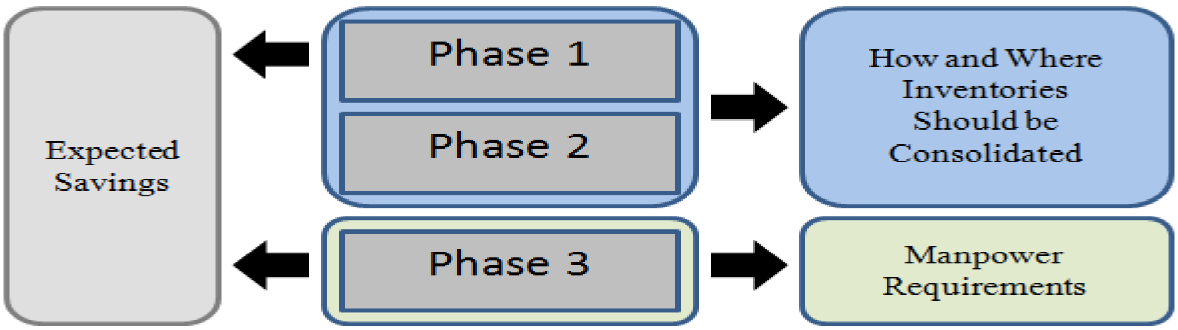
Given the problem's inherent complexity, the AFCEC requested the assistance of the Air Force Institute of Technology (AFIT) to analyze the alternatives to the status quo. Specifically, the following areas were investigated to facilitate equipment posture decision-making: initial implementation cost, risk exposure, and expected manpower requirements.

Research Approach

Due to multiple decision criteria, a phased approach was employed to independently examine initial implementation cost, risk exposure, and manpower requirements. Each topic is then integrated to meet the overall research objective of determining how and where equipment UTCs should be postured within a consolidated structure and what manpower requirements are needed to sustain such an effort. Additionally, potential savings resulting from the proposed alternatives are reported.

The scope of this thesis is limited to the three areas of focus. It does not consider impacts on home station training through the removal of equipment UTCs from current base-level units. Furthermore, the scope is narrowed to include only the CONUS and does not account for equipment UTCs presently postured at overseas locations such as the United States Air Forces in Europe (USAFE) or Pacific Air Forces (PACAF). The ensuing sections further describe the scope specific to each phase, identified as one through three, to include the research objectives, methodology, implications, and limitations. Figure 1 provides a graphical depiction of how each phase is integrated to complete the overall research effort.

Figure 1: Research Approach



Phase One

The first phase investigates the concepts of consolidation and forward placement of equipment inventories through relevant literature to validate the research sponsor's proposed COAs. Each concept is reviewed to determine both benefits and drawbacks of pursuing alternative supply chain structures. Furthermore, the topic of implementation cost is addressed through the following two research objectives:

1. Report the minimum transportation costs required to implement consolidation at one or more locations through optimization
2. Report the subsequent payback periods generated from the reduced transportation burden

A linear programming methodology was utilized to determine the two decision-making criteria. Posturing data provided by AFCEC is compiled into a matrix identifying the location of all equipment UTCs. The matrix is then coupled with transportation costs to ship a particular UTC from its current location to the candidate sites. The linear programming optimization technique is then applied and results are codified. The analysis ultimately answered how and where inventories should be consolidated to minimize initial implementation cost and expected savings are reported.

While the Phase One investigation provides significant insight for determining which alterative option to pursue with regard to cost, the analysis does have certain limitations. For instance, the linear optimization technique does not account for economies of scale nor time value of money. In addition, the reported implementation cost within the study is limited solely to transportation; though, it is expected initial facility construction, operations, and maintenance costs could affect overall decision-making. It should be noted the AFCEC is investigating these areas of interest.

Phase Two

The second phase investigates risk exposure and its relation to supply chain structure. A thorough review is conducted concerning external supply chain disruptions and available mitigation techniques that can be employed to reduce their impact. Increased emphasis is put on adverse weather disruptions due to their significant impact on supply chains and geographical decisions. Furthermore, risk exposure is quantified through the following two research objectives:

1. Report the probability and severity of an adverse weather event occurring at any location for each alternative posturing option
2. Report the probability and severity of an adverse weather event occurring at all locations simultaneously for each alternative posturing option

A descriptive statistics methodology is utilized to determine the two decision-making criteria. Historical data collected from the Spatial Hazard Events and Losses Database for the United States (SHELDUS) are compiled to provide a statistical profile of past adverse weather occurrences at each candidate location. The profiles are examined over a specified time period to determine the required probabilities for comparison. Similar methods are utilized to produce severity estimates. Results are then tabulated to answer how and where inventories should be consolidated to minimize adverse weather disruption risk exposure.

While the Phase Two investigation provides significant insight for determining which alterative option to pursue in regards to risk, the analysis does have certain limitations. For instance, the statistical profiles developed for each candidate location are only as accurate as the data recorded within the SHELDUS. Furthermore, the study captures only adverse weather disruptions and does not account for other disruption categories such as terrorist attacks, labor strikes, or epidemics.

Phase Three

The third phase investigates manpower implications deriving from consolidation and assignment of dedicated personnel to manage, report, handle, and maintain CE equipment UTCs. A review is conducted concerning the current and future states of equipment posture and how each state has and will potentially effect force requirements. Expected manpower requirements and savings are quantified for the alternative posturing options through the following three research objectives:

1. Report the current level of manpower expended to support inventory operations for the geographically dispersed equipment posture
2. Report aspects of both consolidation and assignment of dedicated personnel that hold potential for manpower efficiency
3. Report the expected manpower efficiency should consolidation and assignment of dedicated personnel be pursued

A descriptive statistics and simulation methodology is utilized to determine the first decision making criteria. Manpower data collected by the AFCEC are examined, descriptive statistics generated, and then a simulation conducted to ascertain the number of man-hours expended accomplishing all duties associated with each category of equipment UTC; these figures serve as the manpower baseline. The latter two decision criteria are uncovered employing the Delphi technique and then coupled with the former to codify expected manpower requirements and savings should consolidation be pursued.

While the Phase Three investigation provides significant insight for the potential manpower efficiency gained through consolidation, certain limitations do exist in regards to the CE community study. For instance, the data collected by the AFCEC only captures active duty personnel inputs. Accordingly, results are only representative of that population and do not extend to Air Reserve Component (ARC) units. Moreover, the level of analysis conducted does not delineate between single- or dual-location consolidated structures. Further research is required to achieve such scrutiny.

Outline of the Thesis Document

This thesis takes on the scholarly article format. As such, three articles are presented hereafter with each capturing one of the three phases. Within each article, sections consist of a literature review, methodology, results, and conclusion. The literature review uncovers relevant information and concepts for the phase being investigated. The methodology details the exact process by which available data is examined and subsequently employed to determine research objectives. The results and conclusion sections summarize findings and provide a synopsis of impact. Following the three articles, all findings are integrated and implications discussed to produce final conclusions and recommendations.

II. Scholarly Article: Strategic Positioning of United States Air Force Civil Engineer Contingency Equipment within the Supply Chain

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Abstract

Organizations incur significant costs to transport equipment and goods within the supply chain. In fact, transportation costs related to logistics accounted for over five percent of the United States gross domestic product in 2011, which sums to roughly $800 billion (Burnson, 2012). Given the considerable expense, organizations commit valuable resources and innovation to structure supply chains to minimize funds allocated toward moving goods. The study presented herein analyzes a military specific case involving the consolidation and forward positioning of equipment to minimize transportation costs accrued delivering items to customers. Explicitly, the analysis presented utilizes a linear optimization model to select a central, forward facility among several identified candidate locations and generates subsequent payback periods from the reduced transportation burden. Results suggest the proposed strategic positioning of equipment decreases supply route mileage as well as dependent customer wait time and transportation costs.

Key Words

Supply Chain; Consolidation; Forward positioning; Facility location; Payback period

Introduction

In 2011, logistics costs accounted for $1,282 billion and 8.5% of the United States gross domestic product; transportation costs attributed $816 billion, roughly 64%, to the reported totals with carrying costs contributing the remainder (Burnson, 2012). Given the considerable expense, organizations commit valuable resources and innovation to structure supply chains to minimize funds allocated toward moving goods. The practice is no different for the management and placement of inventories for military operations (Joint Chiefs of Staff, 2013). In fact, the issue appears more pressing in military settings that necessitate rapid closure time to support mission requirements and mitigate casualties resulting from enemy actions. The matter is compounded due to recent fiscal constraints imposed by sequestration, reducing the operating budget of the armed services by $500 billion over the next decade. Such cuts to military spending will force the Department of Defense (DoD) to adopt new, innovative strategies for executing national defense measures to include the transportation of equipment and forces. If not, serious degradation of readiness and capabilities will be realized (Hagel, 2013). An area for innovative application and cost-savings to off-set implications of sequestration presents itself in the context of military logistics.

Given the ever-increasing constraints on government funding and the need for military forces to rapidly achieve closure time on objectives, the ability to reduce transportation costs and delivery times of equipment becomes exceedingly critical. Research in the area of military logistics indicates pre-positioning assets forward in the supply chain to meet future demand of combat, peace-keeping, and humanitarian forces realizes significant cost and time savings (Skipper, Bell, Cunningham, and Mattioda, 2010). In addition to forward placement, research also suggests inventory consolidation facilitates economies of scale, warehouse management improvement, and safety stock reduction (Patton, 1986). Employed together, both consolidation and forward positioning provide the efficiency and effectiveness needed to implement a lean and responsive military supply chain. Furthermore, coupling the concepts with scalable UTCs facilitates a postponement strategy, ensuring that demand overseas is more accurately matched through the use of generalized product classes and forecasting towards the end of the supply chain. Yet, how and where to place contingency inventories to realize the aforementioned benefits requires a strategic decision that is not always readily apparent. The case study presented in this article offers both insight and instruction for determining the placement of contingency equipment in support of the full range of military operations (ROMO).

Background & Problem Statement

The United States Air Force (USAF) Civil Engineer (CE) community, much like other functional areas, manages equipment specific to military response of combat and non-combat operations. The equipment consists of materials used to construct, maintain, and repair infrastructure required for the support and sustainment of military forces. In order to transport assets into overseas theater locations, equipment is bundled into Unit Type Codes (UTCs) to create modular packages tailored to meet particular mission sets. Presently, the UTCs are dispersed throughout the continental United States (CONUS) at various USAF active duty, reserve, and Air National Guard (ANG) bases. Due to the distributed posture, the Air Force Civil Engineer Center (AFCEC) regularly cites inconsistencies with regard to handling, tracking, and capability reporting; in addition to inconsistencies, system redundancies are also evident which create unneeded waste (AFCEC, 2012). Furthermore, the geographical separation requires several points of contact to transfer UTCs for overseas operations, ultimately creating a protracted, cumbersome deployment process (Overstreet, 2004). As a result, the CE community began reviewing alternative options for equipment UTC posture within the CONUS. The review established three courses of action:

1. Maintain current dispersed posture
2. Establish one CONUS holding location near a Port of Embarkation (POE)
3. Establish two CONUS holding locations, one on the west and east coast near a POE

Each course of action takes into consideration 832 equipment UTCs maintained by 163 USAF active duty, reserve, and ANG units; the current layout positions the equipment UTCs at 116 separate locations. Furthermore, the two alternatives to the status quo must also account for current plans to reduce the total number of UTCs postured. Table 1 provides current number postured, reduced number postured, and a description for each respective UTC category.

Table 1: Equipment UTC Description

UTC	Current Total	Reduced Total	Description
4F9EE	143	65	Pest Management Support Equipment
4F9EF	97	34	Sustainment Follow-on Equipment Set
4F9EH	130	49	Survey Support Equipment Set
4F9ET	108	49	Engineer Sustainment Equipment Set
4F9FE	22	6	Firefighter Communications Package
4F9FF	18	8	Firefighter SCBA Compressor
4F9FJ	149	57	Firefighter Management 2 PK Team
4F9FX	18	3	Firefighter Limited Equipment Set
4F9WL	22	10	Active CBRN Response
4F9WN	20	14	CBRN Detection
4F9WP	20	15	CBRN Detection Augmentation
4F9WS	20	9	CBRN Personnel Decontamination
4F9X1	19	19	EOD Core Equipment
4F9X3	2	2	EOD Base Support Sustain Equipment
4F9X6	29	29	EOD Vehicle Support Package
4F9X7	15	15	EOD Large Robotics Platform
TOTALS	832	384	

(DAF, 2011a; AFCEC, 2013a)

Given the problem’s inherent complexity, the CE community enlisted the help of the Air Force Institute of Technology (AFIT) to analyze the alternative options for equipment UTC posture within the CONUS. Specifically, the analysis determines two key decision-making criteria:

1. Report the minimum transportation costs required to implement consolidation at one or more locations through optimization
2. Report subsequent payback periods generated from the reduced transportation burden

The two decision criteria will ultimately answer the how and where to place contingency equipment to achieve minimum re-location costs and payback period. Lastly, the study considers only those UTCs positioned within the CONUS and reflects the posture reported by the AFCEC in January of 2013.

Literature Review

In order to understand the full context of the problem and validate the research sponsor’s proposed courses of action, an extensive literature review was conducted. Each ensuing section presents research completed in subject areas pertinent to the military case study. The initial subject area documents military doctrine, plans, and policy relevant to strategic placement of readiness assets. Successive sections examine aspects of consolidation, forward positioning, facility location, and payback period.

Military Doctrine, Plans, & Policy

Throughout the different branches of military service and various functional areas, units rely on military doctrine, plans, and policy to guide the execution of established mission requirements. DoD, Joint, Department of the Air Force (DAF), and CE governing documents all emphasize the importance of logistics and the need to pre-position rapidly deployable equipment in support of the ROMO. For instance, the Chairman of the Joint Chiefs of Staff (CJCS) stresses the concept of “focused logistics,” summarized as the ability to mobilize forces and equipment at the right place and time to combat enemy actions. A key component required to implement focused logistics comes in the form of pre-positioning equipment (CJCS, 1996; CJCS, 2000). The Air Force echoes the same necessity for pre-positioning through the established core function of Agile Combat Support which encompasses the sustainment of deployed units. This core function has direct implications for many support functional areas to include CE; furthermore, the CE community explicitly states contingency operations support depends on the pre-positioning of deployable equipment (DAF, 2011a; DAF, 2011b; DAF, 2011c; DAF, 2013).

As an example, the USAF currently maintains thirteen sites throughout the world to stage Basic Expeditionary Airfield Resources (BEAR) equipment required to initiate airfield operations in austere environments (Mitchell, Reilly, and Cisek, 2011). While the equipment suffices to start operations, it does not have the capability to sustain mission sets for prolonged periods of time without complementary systems and equipment (DAF, 2011a; DAF, 2012). Hence, the CE community is examining the same pre-positioning concept for its CONUS equipment UTCs to augment BEAR assets and further provide installation sustainment capabilities. In addition to the USAF pre-positioned equipment, the Navy, Marine Corps, Army, and Defense Logistics Agency also maintain overseas inventory sites to support service specific mission requirements. Table 2 provides a listing of the number of sites managed by each service.

Table 2: Number of Overseas Pre-positioning Sites by Service

Service	# of Pre-positioning Sites
Army	8
Air Force	13
Navy	3
Marines	9
Defense Logistics Agency	17

(McGarvey *et al.*, 2010)

From this review, one can see pre-positioning is a fundamental concept of operations captured throughout military governing documents and real world application, ultimately supporting the proposed forward positioning of equipment UTCs by the CE community.

Consolidation

Inventory consolidation consists of storing stock at one or more central locations to satisfy market demand. Such an action often realizes various benefits within the supply chain. Maister (1976) proposed a guiding rule, termed the “square root law” (SQL), which mathematically approximates reductions in overall safety stock as a result of using fewer inventory holding locations. Eppen (1979) demonstrated consolidation outperforms decentralized supply structures with respect to holding and penalty costs using a newsboy type problem. Zinn, Levy, and Bowersox (1989) developed the Portfolio Effect (PE) which eliminated several impractical assumptions of the SQL. The PE provides percent reduction in overall safety stock accomplished through consolidation of several locations into one. The PE has since been challenged, enhanced, and expanded to eliminate underlying assumptions and fit more general models of the supply chain by several authors (Ronen, 1990; Mahmoud, 1992; Tallon, 1993; Evers and Beier, 1993; Tyagi and Das, 1998). These studies reiterate the benefit of reduced inventory holdings realized by consolidation through pooling. Such an effect facilitates the reduction of equipment UTCs currently proposed by the CE community.

Continuing the area of study, Evers and Beier (1998) utilized empirical data to compare PE formulations; the data indicated consolidation savings as a function of lead time. Their reported conclusions suggest inventories should be consolidated to the location experiencing the lowest average and least varying lead time. The findings assist in constraining the candidate consolidation locations for the military case presented. For instance, since all equipment UTCs deploy from the CONUS to various operational areas overseas, candidate locations become restricted to those near POEs. The constraint is imposed because coastal locations are at the end of the CONUS supply chain; thus, sites near POEs experience the shortest lead time in delivering equipment to military personnel.

Accounting for holding and transportation costs, Das and Tyagi (1997) examined several models to determine the optimal level of consolidation. The models verified centralization as ideal when the supply chain experiences high holding costs and low transportation costs. In contrast, the models supported decentralization as ideal when the opposite occurs. However, in context of the CE community problem, the use of one or more consolidation locations near POEs effectively eliminates the transportation burden within the CONUS. Therefore, the only salient factor becomes holding costs, which is best mitigated through centralization.

Applying a more qualitative approach, Nair (2005) explored the link between centralized distribution and performance. Using a survey, Nair collected positive replies from ten separate industry groups, including 306 Council of Logistics Management members. The survey results supported centralized distribution as positively related to “asset productivity, delivery competence, and responsiveness” (Nair, 2005). The findings complement those by Patton as shown in Table 3.

Table 3: Benefits of Consolidation

Reduced factory to distribution transport costs	Better warehouse management	Consistent stock availability
No cross-hauling between locations	Reduced stock holdings	Economies of scale
Better transportation negotiation	Improved automation	Improved stock turnover

(Patton, 1986)

Furthermore, Wanke and Saliby (2009) utilized a consolidation effect model to compare total operating costs between independent systems, regular transshipments, and centralized supply chains. Their study derived from distribution, holding, and processing costs. Sensitivity analysis of the model resulted in 10,000 simulated scenarios with 9,107 cases showing minimum total costs achieved from inventory consolidation.

Considering the benefits identified through the literature thus far, the CE community appears validated in pursuing a central structure of inventory holdings. However, consolidation does not come without negative aspects as well. Patton (1986) identified several such issues that must be balanced when determining supply chain structure to include longer customer order cycle times, increased transportation costs, and decreased sales due to less availability. Fortunately, forward positioning has the ability to mitigate increased cycle time and transportations cost issues as demonstrated in the next section of literature; whereas, the issue of decreased sales is irrelevant to the military case study.

Forward Positioning

Forward positioning generally refers to the advanced placement of inventory in close proximity to the end-user. Several reasons exist for utilizing pre-positioned inventories; Ho and Perl (1995) capture one reason in an examination of service-sensitive demand with respect to warehouse location. Their analysis suggests markets with more sensitivity to service require a shorter delivery cycle time, and recommends achieving higher responsiveness to sensitivity by placing needed goods closer to the customer. Meeting service-sensitive demand proves critical in military operations—shorter delivery cycle times ensure the right equipment and forces are placed in position to effectively combat enemy actions. In fact, a significant number of studies concerning the issue examine and suggest forward positioning as a solution for such demand, indicating reduced closure time and transportation costs as typical results (Overstreet, 2004; McNulty, 2003; Amouzegar, Tripp, and Galway, 2004; Ghanmi and Shaw, 2008; McCormick, 2009; Skipper *et al.*, 2010).

Dekker *et al.* (2009) reported similar findings pertaining to cycle time and costs by considering “floating stock” which deploys products forward by rail before customer demand is finalized. Two of the referenced articles bear similarity to the military case study being examined. For instance, Overstreet (2004) led a study conducted by the Air Force Logistics Management Agency (AFMLA), capturing the benefits of forward positioning and consolidation of medical equipment UTCs. Skipper *et al.* (2010) conducted a comparable analysis of security forces UTCs by using optimization to ascertain transportation cost-savings for candidate storage locations forward in the supply chain. While not specific to equipment UTCs, Amouzegar *et al.* (2004) applied an analytical approach to facilitate pre-positioning and deployment policy while accounting for deployment time, employment time, airlift, site costs, and transportation costs. Conclusions implied using a forward location can increase efficiencies and readiness rates. Ghanmi and Shaw (2008) employed historical data to review pre-positioning for Canadian Forces. For the specific case assessed, closure time reduced by twelve days and costs related to airlift decreased by 17% through advanced placement.

The literature highlights substantial benefits realized through the use of forward positioning, especially when coupled with consolidation. Specifically it helps to mitigate the rise in transportation costs and increased cycle times experienced through consolidation alone. However, as with consolidation, negative aspects of forward positioning must also be considered such as the possibility of limited access to assets if positioned on foreign land or at sea, and assets requiring re-positioning due to the area of interest or demand moving (Lee, 1999).

With the area of interest or demand overseas, the CE community's proposal to site consolidated inventories near POEs within the CONUS considerably mitigates the aforementioned negative aspects. Each POE, located on a coast of the United States, positions the equipment UTCs closer to the area of interest while simultaneously eliminating unneeded transportation from the dispersed bases. Furthermore, maintaining sites within the CONUS avoids accessibility problems and eases the implementation of force protection requirements. As a result, the proposal of consolidating and forward positioning CE equipment UTCs as opposed to operating with a dispersed supply structure appears to be validated. While this identifies and constrains candidate locations, the exact method for determining how and where to locate inventory is still unanswered.

Facility Location

Determining facility location requires a complex decision, often needing significant review and analysis. To facilitate such decision making, Weber (1929) proposed a formulation which allowed organizations to choose the least cost option for facility location by minimizing the expenses tied to transportation. Present day processes and mathematical formulations applied to location analysis vary depending on user objectives, but almost all models are derived from the Weber problem (Drezner, Klamroth, Schobel, and Wesolowsky, 2002).

Drezner and Hamacher (2002) capture and explain, with the contribution of several works, the Weber formulation and many of its variations applicable to different problem sets. Of particular interest are the eight discrete network location models (set covering, maximal covering, *p*-center, *p*-dispersion, *p*-median, fixed charge, hub, and maxisum) presented by Current, Daskin, and Schilling (2002) that are applicable to the CE equipment UTC problem. The facility location model category of "discrete network" refers to a problem set whose number of candidate locations remains fixed, known with certainty, and part of the already existing system (Drezner and Hamacher, 2002). Daskin (1995) expands on several of the eight models by presenting different methodologies to determine solutions which include linear programming, heuristic algorithms, graph-theoretic algorithms, and Benders decomposition.

These methods, as well as others proposed in the area of location analysis, have been used for siting military facilities, equipment, or personnel (Schick, 1992; Dawson, Bell, and Weir, 2007; Overholts II, Bell, and Arostegui, 2009; Rowe, 2009; Skipper *et al.*, 2010; Bell, Griffis, Cunningham, and Eberlan, 2011). For example, Dawson, Bell and Weir (2007) applied a combination of *p*-median and *p*-center models to determine the optimal position for security forces teams implementing protection measures for intercontinental ballistic missiles (ICBMs). Overholts II, Bell, and Arostegui (2009) used a maximal covering location model to facilitate an improved maintenance schedule for missile launch facilities. Both Rowe (2009) and Skipper *et al.* (2010) used linear programming models to determine facility location based on minimum transportation costs amongst several candidate sites. Bell *et al.* (2011) determined number and location options for aircraft alert sites using a combination of set covering, *p*-median, and *p*-center models.

Considering similarities with regards to problem type, the linear programming methods used by Rowe (2009) and Skipper *et al.* (2010) present a framework for ascertaining optimal consolidation location(s) for CE equipment UTCs. Each study employs a formulation modified from the transportation model presented by Daskin (1995). The modifications were necessary to account for problem specific constraints and criteria such as number of candidate consolidation locations and shipping costs. Examples of transportation models abound in the operations research and management science literature. For instance, most operations research texts provide simple explanations for identifying, framing, and solving transportation problem sets (Ragsdale, 2004; Rader, 2010).

Given that the CE community requires a minimum cost solution for consolidation, the problem lends itself directly to a linear programming transportation model. Solutions to these models provide answers of how and where to place contingency equipment to achieve minimum re-location costs.

Payback Period

A simple economic tool, average payback period, facilitates decision making for investments. One of the more widely employed methods for analyzing investment decisions, its use can be found throughout industry sectors. Generally, average payback period captures the elapsed time required for an organization to accumulate enough profit or savings from an investment to pay off the initial costs of implementing the investment (Eschenbach, 2011). The mathematical formulation is represented by Equation 1. Table 4 presents several advantages and disadvantages associated with utilizing average payback period.

$$Average\ Payback\ Period = \frac{Investment\ Cost}{Average\ Cash\ Inflow\ per\ Period} \qquad (1)$$

Table 4: Average Payback Period Pros/Cons

Advantages	Disadvantages
Ease of use	Disregards time value of money
Consideration of cash flows	Disregards succeeding cash flows
Risk measurement	Cash inflows are speculative

(Cotts, Roper, and Payant, 2010)

Due to the disregard for time value of money, many engineering economists do not recommend the use of payback period (Eschenbach, 2011). However, as described in what follows, when comparing alternatives whose period is defined based on event occurrence rather than on time elapsed, the method's ease of use can be preferable.

For the specific transportation problem set at hand, the determination of payback period provides the CE community indications of which equipment UTC posture to pursue. Essentially, it quantifies the transportation savings, if any, per period achieved from forward positioning and determine whether those savings are substantial enough to warrant inventory consolidation. However, in reviewing available literature, only one study utilizes average payback period for analyzing strategic placement of inventory while concurrently executing consolidation. The lack of literature examining average payback period for similar problem sets does not invalidate the use of such a method, but it does offer limited insight in developing the framework for analysis. The referenced study, conducted by Skipper *et al.* (2010), considered the consolidation of security forces UTCs at several candidate sites while applying a linear programming methodology to obtain average payback period. The method directly applies to the CE community problem and easily adapts to encompass the differing model parameters.

One beneficial aspect of the model applied by Skipper *et al.* (2010) is the use of event occurrence rather than elapsed time for the period. Given the CE community could not provide accurate historical data on equipment UTC taskings, using such a method reports payback as achieved in a certain number of event occurrences as opposed to number of years passed. Even with accurate data, the number of equipment deployments in a given year proves highly variable due to the nature of military operations; therefore, event occurrence best captures the average payback period. In addition, since linear programming is utilized to determine minimum transportation costs to consolidate, the same model can be applied to accurately determine payback period; in fact, only a few modifications with respect to problem constraints are required. The methodology section fully explains these required changes. Lastly, the proposed modified framework, answers how and where to place contingency equipment to achieve minimum payback periods.

The literature presented offers both context and methods for understanding and solving the CE equipment UTC problem. Reviewing military doctrine, consolidation, and forward positioning publications helped to validate the CE community proposal for pursuing a more central, forward supply chain structure. The subsequent sections examining facility location and payback period helped to develop a framework and methodology for carrying out analysis. Such analysis provides CE senior leaders the pertinent information needed to decide on the future equipment UTC posture. The remaining sections presented outline the exact methodology used to model and solve the problem as well as the results obtained through analysis.

Methodology

Single-Location Consolidation

The objective of the single-location consolidation problem set is to determine which candidate site facilitates the centralization of equipment UTCs, while achieving minimum transportation costs. Explicitly, an optimization model is used to identify which UTCs must be shipped from each of the dispersed base locations to a single consolidation location to satisfy reduced equipment UTC totals, while simultaneously minimizing transportation costs. Table 5 lists candidate sites considered for analysis as requested by the research sponsor.

Table 5: Candidate Consolidation Locations

East Coast	West Coast
Charleston AFB	March ARB
Dover AFB	Travis AFB
McGuire AFB	McChord AFB
Westover ARB	-

(AFCEC, personal communication, January, 2013)

Acknowledging land-based delivery as the predominant method for transferring UTCs within the CONUS, trucking transport costs were compiled using the Global Freight Management (GFM) rate quotation application maintained by the Military Surface Deployment and Distribution Command. Rates quoted reflect the shipment of a single equipment UTC weighing an average of 4,700 pounds on a 40 foot, flatbed trailer (GFM, 2013; AFCEC, 2013b). All reported costs are point estimates and do not account for market variations over time. Table 6 captures the cost matrix derived from these quotes, listing only a sample of the bases for purposes of brevity.

Table 6: Transportation Cost Matrix

	Consolidation Locations						
AFBs	Charleston	Dover	McGuire	Westover	March	Travis	McChord
Hurlburt	722	1166	1236	1401	1832	1884	2145
Barksdale	1162	1554	1599	1844	1797	2288	2704
Minot	1445	2162	2176	1446	2100	2025	1557
MacDill	630	1108	1185	1352	1867	2190	2389
Dyess	1444	1808	1879	2112	1272	1768	2141
Beale	2004	2006	2023	2092	927	618	1015
Bolling	793	510	466	716	2325	2475	2446
Shaw	543	824	903	1083	2110	2445	2550
Peterson	1830	1841	1867	2078	1127	1352	1501
McConnell	1504	1686	1600	1797	1613	1956	2194
Moody	455	1226	1144	1398	1974	2346	2543
Cannon	1702	1957	1984	2227	1081	1493	1853
Ellsworth	1405	2145	2157	1435	1661	1729	1479
Patrick	585	1074	1149	1318	1913	2236	2421

(GFM, 2013)

In addition to the cost data, AFCEC provided the current posturing of all equipment UTCs throughout the world. All posturing documents provided by the research sponsor were segregated by type and listed every location holding the particular equipment UTC. To facilitate the study, a compiled posturing matrix was created which reported locations only within the CONUS to include respective equipment UTC types and totals held. Several of the locations listed account for multiple units stationed at the same base or in close proximity of each other. Table 7 depicts the posturing matrix, again shortened for conciseness.

Table 7: Equipment UTC Posture

	UTC Category								
AFBs	4F9ET	4F9EF	4F9EH	4F9EE	4F9FE	4F9FF	4F9FJ	4F9FX	**Total**
Hurlburt	1	0	1	1	0	0	0	0	3
Barksdale	2	2	2	2	1	1	3	0	13
Minot	1	3	1	2	0	1	1	0	9
MacDill	0	0	0	0	0	1	1	1	3
Dyess	1	2	1	1	1	1	1	0	8
Beale	2	3	2	2	0	0	3	1	13
Bolling	1	0	0	0	0	1	1	1	4
Shaw	1	3	1	2	1	0	1	1	10
Peterson	1	2	1	3	0	0	0	0	7
McConnell	2	3	3	3	0	1	1	1	14
Moody	1	2	1	1	0	1	1	0	7
Cannon	1	2	1	1	0	1	1	1	8
Ellsworth	1	2	1	2	1	0	1	1	9
Patrick	0	2	0	2	0	0	1	0	5

(AFCEC, 2013b)

After collecting all necessary data, the Daskin (1995) transportation formulation was applied with modifications imposed to reflect problem specific parameters. The linear programming model, represented as follows, considers only one consolidation location at a time (Skipper *et al.*, 2010):

$$\text{Minimize:} \quad Z = \sum_{i=1}^{m} \sum_{k=1}^{l} x_{ik} a_{ik} \tag{2}$$

Subject to:

$$a_{ik} \leq s_{ik} \quad \text{for } i = 1, 2, \ldots, m \text{ and } k = 1, 2, \ldots, l \tag{3}$$

$$\sum_{i=1}^{m} a_{ik} = t_k \text{ for the selected consolidation location and } k = 1, 2, \ldots, l \tag{4}$$

Where:

Z = total transportation cost per consolidation location

a_{ik} = number of equipment UTCs of type *k* shipped from base location *i* to the selected consolidation location

x_{ik} = transportation cost for equipment UTC of type *k* shipped from base location *i* to the selected consolidation location

s_{ik} = number of equipment UTCs of type *k* postured at base location *i*

t_k = number of equipment UTCs of type *k* required at the selected consolidation location

To execute the model, all inputs were programmed into LINGO 11.0 and successively run to optimality for each candidate consolidation location. Results are reported in Table 11 of this article. In addition, Table 8 posts all assumptions required to implement the analysis.

Table 8: Consolidation Analysis Assumptions

1	Manning is available or will be transferred for inventory control and maintenance to consolidation points
2	Facility housing is available or will be made available for storing equipment UTCs at consolidation points
3	UTCs will be delivered in the same condition as picked up by the transportation provider (i.e. no damage, loss, or theft)

Dual-Location Consolidation

The objective of the dual-location consolidation problem set is to determine which east and west coast pair of candidate sites facilitates the centralization of equipment UTCs, while achieving minimum transportation costs. Explicitly, an optimization model is used to identify which UTCs must be shipped from each of the dispersed base locations to an east and west coast consolidation location to satisfy reduced equipment UTC totals, while simultaneously minimizing transportation costs. Capitalizing on the single-location model, all aspects of the problem remain the same with exception of the formulation which requires minor adjustments. The candidate consolidation locations, transportation cost matrix, equipment UTC posture, and assumptions required no changes. The linear program model represented as follows, considers only one east and west coast pair at a time (Skipper *et al.*, 2010):

$$\text{Minimize:} \quad Z = \sum_{i=1}^{m}\sum_{k=1}^{l} x_{ik}a_{ik} + \sum_{i=1}^{m}\sum_{k=1}^{l} y_{ik}b_{ik} \qquad (5)$$

Subject to:

$$a_{ik} + b_{ik} \leq s_{ik} \quad \text{for } i = 1, 2, \ldots, m \text{ and } k = 1, 2, \ldots, l \qquad (6)$$

$$\sum_{i=1}^{m} a_{ik} = t_k \text{ for the selected consolidation location and } k = 1, 2, \ldots, l \qquad (7)$$

$$\sum_{i=1}^{m} b_{ik} = u_k \text{ for the selected consolidation location and } k = 1, 2, \ldots, l \qquad (8)$$

Where:

Z = total transportation cost per consolidation location pair

a_{ik} = number of equipment UTCs of type *k* shipped from base location *i* to the west coast consolidation location

b_{ik} = number of equipment UTCs of type *k* shipped from base location *i* to the east coast consolidation location

x_{ik} = transportation cost for equipment UTC of type *k* shipped from base location *i* to the west coast consolidation location

y_{ik} = transportation cost for equipment UTC of type *k* shipped from base location *i* to the east coast consolidation location

s_{ik} = number of equipment UTCs of type *k* postured at base location *i*

t_k = number of equipment UTCs of type *k* required at the west coast consolidation location

u_k = number of equipment UTCs of type *k* required at the east coast consolidation location

Again, all inputs were programmed into LINGO 11.0 and successively run to find an optimal solution for each east and west coast pair. Results for the twelve different options are reported in Table 12. For the dual-location configuration, the required number of consolidated equipment UTCs were split evenly between the east and west coast locations unless the joined total was uneven. In such an event, the unpaired equipment UTC was allocated to the west coast site. No particular justification is provided for choosing the west coast, other than the research sponsor indicated no preference.

Average Payback Period

The objective of the average payback period problem is to determine the number of periods required to achieve payback of the initial investment, where initial investment is the transportation cost required to implement a single- or dual-location consolidation configuration. In order to accomplish this aspect of the study, the AFCEC derived a standard equipment UTC tasking typically used to open contingency airbases from the *Civil Engineer Supplement to the War and Mobilization Plan-1* (DAF, 2011a; AFCEC, personal communication, May, 2013). The standard tasking, depicted in Table 9, accounts for the bed-down of 3,300 personnel to support aircraft operations in a medium threat area.

Table 9: Standard Equipment UTC Tasking

UTC	#	UTC	#	UTC	#	UTC	#
4F9ET	3	4F9EF	4	4F9EH	3	4F9EE	1
4F9WL	1	4F9WN	1	4F9WP	1	4F9WS	2
4F9X1	1	4F9X3	1	4F9X6	1	4F9X7	1
4F9FE	1	4F9FF	1	4F9FJ	1	4F9FX	1

(DAF, 2011a; AFCEC, personal communication, May, 2013)

After receiving standard tasking parameters from the research sponsor, the two models previously outlined for single- and dual-location configurations were applied. However, the constraints were modified to reflect only the equipment UTC totals needed to fill the standard tasking rather than the reduction numbers listed in Table 1. For the single-location analysis, one standard tasking was filled at the selected consolidation location. For the dual-location analysis, two standard taskings were filled—one on the east and west coast, respectively. The summation of the east and west coast transportation cost was then halved to arrive at an average cost to fill one standard tasking between the two locations. Once the transportation cost to fill the standard package(s) for each option was optimized, it was matched with the cost to consolidate the reduction totals previously determined. The two costs were applied to Equation 1, with the cost to consolidate the reduced totals of equipment UTCs being the investment cost; and the cost to transport the standard tasking(s) for deployment being the average cash inflow per period (Note: the period referenced indicates the event of a standard tasking deployment).

Lastly, the assumptions required for average payback period analysis are identical to those used in the single- and dual-location problem sets. Yet, three others are required which are detailed in Table 10. The third assumption listed in Table 10 is applied because equipment UTCs presently at the candidate consolidation location(s) under analysis do not contribute transportation savings to the payback period.

Table 10: Average Payback Period Assumptions

1	All equipment UTCs considered within the study meet necessary readiness requirement to immediately deploy
2	All equipment UTCs deployed do not return from overseas; therefore, no reverse logistics savings are realized
3	Equipment UTCs positioned at the selected candidate consolidation location under analysis are not considered for determination of the payback period

Results

Single-Location Consolidation

Table 11 presents results for the single-location consolidation problem. The price range to transport the 384 equipment UTCs identified by the research sponsor for centralization is $352 to $577 thousand, where Dover AFB and McChord AFB represent the lower and upper bounds, respectively. Appendix A provides a matrix indicating which equipment UTCs must be shipped from each dispersed base to achieve the minimum transportation cost of $352 thousand.

Table 11: Single-Location Consolidation Transportation Cost

Charleston AFB	$355,418
Dover AFB	$351,572
McGuire AFB	$362,004
Westover ARB	$420,718
March ARB	$456,221
Travis AFB	$502,350
McChord AFB	$576,873

Dual-Location Consolidation

Table 12 presents results for the dual-location consolidation problem. The price range to transport the 384 equipment UTCs identified by the research sponsor for centralization is $265 to $350 thousand; where March ARB and Dover AFB represent the lower bound pairing. McChord AFB and Westover ARB pair together as the upper bound. Appendix B provides a matrix indicating which equipment UTCs must be shipped from each dispersed base to achieve the minimum transportation cost of $265 thousand.

Table 12: Dual-Location Consolidation Transportation Cost

March ARB	Travis AFB	McChord AFB	
$272,782	$281,054	$328,637	Charleston AFB
$264,762	$272,900	$320,511	Dover AFB
$268,155	$276,291	$323,902	McGuire AFB
$294,527	$302,671	$350,282	Westover ARB

Average Payback Period

Table 13 presents results for the single- and dual-location deployment of a standard tasking. Subsequent payback periods are found in Table 14. Examining the cost to deploy a standard tasking, the use of a forward, central inventory holding location allows for substantial savings. From the reported results, there is an average savings of $13,099 from the reduced transportation burden each time a tasking occurs.

Table 13: Single- and Dual-Location Standard Tasking Transportation Cost

Single-Location Standard Tasking Transportation Cost			
Charleston AFB		$12,352	
Dover AFB		$11,652	
McGuire AFB		$12,051	
Westover ARB		$13,130	
March ARB		$12,507	
Travis AFB		$14,709	
McChord AFB		$16,796	
Dual-Location Standard Tasking Transportation Cost			
March ARB	Travis AFB	McChord AFB	
$12,026	$13,097	$13,882	Charleston AFB
$11,673	$12,744	$13,529	Dover AFB
$11,854	$12,925	$13,710	McGuire AFB
$12,437	$13,508	$14,293	Westover ARB

Table 14: Single- and Dual- Location Average Payback Period

Single-Location Average Payback Period (# taskings)			
Charleston AFB		29	
Dover AFB		31	
McGuire AFB		31	
Westover ARB		33	
March ARB		37	
Travis AFB		35	
McChord AFB		35	
Dual-Location Average Payback Period (# taskings)			
March ARB	Travis AFB	McChord AFB	
23	22	24	Charleston AFB
23	22	24	Dover AFB
23	22	24	McGuire AFB
24	23	25	Westover ARB

The mean payback period for the single-location configuration is 33 standard tasking deployments, Charleston AFB and March ARB representing the lower and upper bounds, correspondingly. 24 standard tasking deployments is the mean payback period for the dual-location structure; Travis AFB and any east coast location, with exception to Westover ARB, pairing together as the lower bound. If the second assumption of Table 10 is eliminated, the realized payback periods are halved due to savings in reverse logistics routing.

Integrating the analysis, it appears the dual-location supply structure offers the best cost option and quickest payback period. However, the outputs do not account for facility life-cycle costs (LCCs) such as initial capital or operations and maintenance expenses, which may alter the final configuration decision. For example, a reasonable assumption may be that maintaining a single, large facility is less expensive than keeping two smaller facilities. The lack of LCC information availability is a limitation of the research. Moreover, the transportation costs reported can be conservatively assumed as over-estimates because the analysis does not account for economies of scale. While this is unlikely to change the outcome of best candidate sites, it will likely lower the overall cost of centralizing the reduced total of 384 equipment UTCs. Again, the inability to model economies of scale with the methodology chosen is a limitation of the research. Even with the identified limitations, the analysis provides objective indication of how and where equipment UTCs should be postured to realize the benefits discussed throughout this article, while simultaneously achieving minimum transportation cost and payback period.

Conclusion

The military case presented indicates a forward, central inventory holding location is beneficial when compared to a dispersed posture. For instance, consolidation of the equipment UTCs mitigate the handling, tracking and capability reporting discrepancies identified by AFCEC. Furthermore, forward positioning of the equipment UTCs reduces the transportation burden of shipping inventory within the CONUS, resulting in significant cost savings. Additional savings could be realized through reduced manpower and warehouse footprint needed to maintain and store equipment (Skipper *et al.*, 2010). Beyond cost savings, response time is enhanced by eliminating an average of two and one-half days transiting equipment UTCs from a dispersed base location to a POE. The research results support consolidation of equipment UTCs near a POE. Recommendations propose a single-location configuration should be sited at Charleston AFB, whereas a dual-location configuration should consist of March ARB and Dover AFB when considering minimum transportation costs. Implementation of either option will increase force readiness and simultaneously realize substantial savings, effectively providing the DoD a military logistics application to help mitigate barriers imposed by future budget constraints.

Further research should be conducted in the areas of facility LCC, manpower requirements, and risk associated with the different supply chain structures to provide comprehensive analysis pertaining to the CE community alternative options. Investigating such information allows senior leaders to examine all aspects of the problem at hand, ultimately leading to an informed, objective solution.

The military case presented has implications for other functional areas within the DoD which maintain a dispersed posture for contingency equipment throughout the CONUS and whose primary purpose for the equipment is to support operations overseas. Other fields of interest are those who experience time-sensitive demand, where delays in equipment delivery result in significant economic or human loss.

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Appendix A

Dover AFB Single-Location Consolidation Equipment UTCs

Base Location	UTC Category																Base Total
	4F9ET	4F9EF	4F9EH	4F9EE	4F9FE	4F9FF	4F9FJ	4F9FX	4F9X1	4F9X3	4F9X6	4F9X7	4F9WL	4F9WN	4F9WP	4F9WS	
Hurlburt	1	0	0	1	0	0	0	0	0	0	2	0	1	1	1	0	7
Barksdale	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
Seymour Johnson	1	2	1	2	1	1	3	0	0	0	1	0	0	0	0	0	12
MacDill	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Bolling	1	0	0	0	0	1	1	1	0	0	0	1	1	1	1	1	9
Little Rock	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	4
Shaw	1	3	1	2	0	0	0	0	1	0	1	0	1	1	1	1	13
Peterson	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	3
McConnell	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Moody	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Cannon	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
Patrick	0	2	0	2	0	0	0	0	0	0	0	0	1	1	1	1	8
Luke	0	0	0	0	0	0	0	0	2	1	6	1	0	0	0	0	10
Travis	0	0	0	0	0	0	0	0	1	0	2	1	0	0	0	0	4
McGuire	2	3	3	3	1	1	3	1	2	0	1	0	1	1	1	1	24
WPAFB	1	1	1	1	0	0	3	0	0	0	0	1	0	0	0	0	8
Dobbins	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Eglin	0	0	0	0	0	0	0	0	3	0	0	1	0	1	1	0	6
Altus	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
Nellis	0	0	0	0	0	0	0	0	2	1	3	1	0	0	0	0	7
Tyndall	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	4
Davis-Monthan	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
Mountain Home	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	2
Scott	2	3	0	3	0	1	0	0	0	0	0	1	1	1	1	1	14
Kirtland	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Grissom	1	1	1	1	0	0	2	0	0	0	0	0	0	0	0	0	6
Dover	2	3	2	4	2	1	3	1	1	0	2	1	1	1	1	1	26
Westover	1	1	1	1	1	0	2	0	0	0	0	0	0	0	0	0	7
March	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Andrews	2	0	2	2	0	0	2	0	0	0	0	0	0	0	0	0	8
Whiteman	1	3	0	4	0	0	0	0	0	0	0	0	0	0	0	0	8
Charleston	1	2	1	1	0	1	3	0	1	0	0	1	1	1	1	1	15
Langley	0	3	2	0	1	1	1	0	0	0	1	1	1	1	1	1	14
Hill	0	0	0	0	0	0	3	0	2	0	0	1	0	0	1	0	7
Lackland	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	3
Maxwell	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	6
Youngstown-Warren	1	0	1	1	0	0	2	0	0	0	0	0	0	0	0	0	5
Pittsburg	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Niagara Falls	2	0	2	2	0	0	3	0	0	0	0	0	0	0	0	0	9

Dover AFB Single-Location Consolidation Equipment UTCs

Base Location	UTC Category																Base Total
	4F9ET	4F9EF	4F9EH	4F9EE	4F9FE	4F9FF	4F9FJ	4F9FX	4F9X1	4F9X3	4F9X6	4F9X7	4F9WL	4F9WN	4F9WP	4F9WS	
Bangor, ME	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Otis ANGB, MA	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Bradley ANGB	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Westfield, MA	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Newburgh, NY	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Westhampton, NY	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Scotia, NY	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Battle Creek, MI	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Robins AFB	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Nashville, TN	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Fargo, ND	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	3
Columbus OH	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Fort Wayne IAP	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Louisville, KY	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Harrison, MI	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Milwaukee, WI	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Charleston, WV	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Knoxville, TN	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
North Kingston, RI	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Charlotte, NC	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Pease ANGB, NH	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
South Burlington, VT	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Memphis, TN	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Garden City, GA	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
New Castle, DE	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Martinsburg, WV	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Eastover, SC	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Coraopolis, PA	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Syracuse, NY	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Baltimore, MD	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Egg Harbor Township, NJ	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Mansfield, OH	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	3
Swanton ANGB, OH	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Terre Haute, IN	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Peoria, IL	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Springfield, IL	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Meridian, MS	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Middleton, PA	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Indiantown Gap, PA	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
UTC Total	49	34	49	65	6	8	57	3	19	2	29	15	10	14	15	9	384

Appendix B

March AFB Dual-Location Consolidation Equipment UTCs

	UTC Category																
Base Location	4F9ET	4F9EF	4F9EH	4F9EE	4F9FE	4F9FF	4F9FJ	4F9FX	4F9X1	4F9X3	4F9X6	4F9X7	4F9WL	4F9WN	4F9WP	4F9WS	**Base Total**
Dyess	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2
Beale	2	0	2	2	0	0	3	0	0	0	0	0	0	0	0	0	9
Peterson	1	0	1	3	0	0	0	0	0	0	0	1	0	1	1	0	8
Cannon	1	0	1	1	0	1	1	0	0	0	2	0	0	0	0	0	7
Vandenberg	0	2	0	2	0	0	1	0	0	0	0	0	1	1	1	1	9
Holloman	1	0	1	2	0	0	1	0	0	0	0	0	0	0	0	0	5
Luke	2	1	2	3	0	0	3	0	2	0	6	1	1	1	1	1	24
Travis	2	4	2	2	1	1	3	0	1	0	2	1	1	1	1	1	23
F.E. Warren	1	0	1	3	0	0	2	0	0	0	0	0	0	0	0	0	7
Nellis	1	3	1	2	1	0	1	1	3	1	3	1	1	1	1	1	22
Grand Forks	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Tyndall	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Davis-Monthan	1	2	1	1	0	0	2	1	1	0	1	0	1	1	1	1	14
Mountain Home	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2
Kirtland	1	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	4
March	2	1	2	2	1	0	2	0	1	0	0	0	0	0	0	0	11
Buckley	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
McChord	2	0	2	2	0	0	2	0	0	0	0	0	0	0	0	0	8
Langley	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Hill	2	0	2	2	0	0	3	0	2	0	0	1	0	1	1	0	14
Lackland	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Fargo, ND	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Portland, OR	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Fresno, CA	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Port Hueneme, CA	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Reno, NV	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Baltimore, MD	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Terre Haute, IN	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Springfield, IL	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
UTC Total	25	17	25	33	3	4	29	2	10	1	15	8	5	7	8	5	197

Dover AFB Dual-Location Consolidation Equipment UTCs

	UTC Category																
Base Location	4F9ET	4F9EF	4F9EH	4F9EE	4F9FE	4F9FF	4F9FJ	4F9FX	4F9X1	4F9X3	4F9X6	4F9X7	4F9WL	4F9WN	4F9WP	4F9WS	**Base Total**
Hurlburt	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
Seymour Johnson	1	2	1	2	0	0	3	0	0	0	1	0	0	0	0	0	10
Bolling	1	0	0	0	0	1	1	0	0	0	0	1	1	1	1	1	8
Shaw	0	3	0	2	0	0	0	0	1	0	1	0	1	1	1	0	10
McConnell	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Moody	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
Patrick	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2
Luke	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
McGuire	2	3	3	3	0	1	3	0	2	0	1	0	1	1	1	1	22
WPAFB	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Eglin	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	4
Tyndall	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	3
Scott	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
Dover	2	3	2	4	2	1	3	1	1	0	2	1	1	1	1	1	26
Westover	1	1	1	1	0	0	2	0	0	0	0	0	0	0	0	0	6
Andrews	2	0	2	2	0	0	2	0	0	0	0	0	0	0	0	0	8
Charleston	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	0	4
Langley	0	3	2	0	1	1	1	0	0	0	1	1	1	1	1	1	14
Lackland	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2
Youngstown-Warren	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Pittsburg	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Niagara Falls	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4
Otis ANGB, MA	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Bradley ANGB	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Westfield, MA	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Newburgh, NY	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Westhampton, NY	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Scotia, NY	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Battle Creek, MI	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Fargo, ND	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Columbus OH	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Charleston, WV	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
North Kingston, RI	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Charlotte, NC	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
Pease ANGB, NH	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2
New Castle, DE	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Martinsburg, WV	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Coraopolis, PA	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3
Syracuse, NY	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	3
Baltimore, MD	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Egg Harbor Township, NJ	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	4
Middleton, PA	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Indiantown Gap, PA	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
UTC Total	24	17	24	32	3	4	28	1	9	1	14	7	5	7	7	4	187

III. Scholarly Article: A Spatial Examination of External Supply Chain Disruptions to Facilitate Strategic Inventory Placement

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Abstract

The United States Air Force (USAF) Civil Engineer (CE) community is currently considering the consolidation of contingency equipment dispersed throughout the United States. Certainly, several areas of research drive the decision on whether or not to centrally position wartime supplies such as cost, risk, and manpower. The contents of this article attempt to provide direction concerning the topic of risk. Explicitly, the article explores the area of supply chain disruptions with a specific focus on external events such as adverse weather.

The frequency and impact of supply chain disruptions is increasing with time; furthermore, environmental conditions such as adverse weather appear to be the most common cause of such disruptions (Stecke and Kumar, 2009; Capgemini, 2012). This article examines the occurrence and spatial relationship of such events within the United States to facilitate the safe placement of CE contingency equipment. The findings provide direction for CE community decision-makers to determine critical inventory holding locations that avoid disruptions.

Key Words

Supply Chain Disruption; Adverse Weather; Civil Engineer; Contingency Equipment

Introduction

Supply chain disruptions continue to present an increasingly significant problem within the logistics community. According to the Business Continuity Institute (BCI) 2011 Supply Chain Resilience Survey, 85% of responding firms experienced a minimum of one disruption, marking an increase of 13% from the previous year; in addition, 17% of the affected firms experienced financial losses in excess of $1.3 million (BCI, 2010; BCI, 2011). Furthermore, environmental conditions, to include natural disasters and smaller adverse weather events, were reported as the principal contributor to the aforementioned disruptions with over 50% of respondents attributing incidents to such events. Many researchers credit the emergent risk of disruption to the increasingly interconnected global supply chain as companies pursue leaner operations with more reliance on outsourced partners (Christopher and Peck, 2004; Hendricks and Singhal, 2005; Stecke and Kumar, 2009). Given the growing impact of supply chain disruptions, organizations, practitioners, and researchers developed, examined, and introduced a variety of mitigation methods to reduce, transfer, or avoid exposure to disruptions (Behdani, Adhitya, Lukszo, and Srinivasan, 2012).

One established practice utilized to effectively mitigate exposure to disruptive events, especially adverse weather, is the placement of facilities or inventories in “safe” locations (Thun and Hoenig, 2011). Under these conditions, a safe location can be defined as an area that exhibits less vulnerability to the identified risk relative to others (Stecke and Kumar, 2009). The private sector often employs this valuable practice as a mitigation tool; however, objectively assigning inventories to safe locations equally applies to the management and placement of inventories for military operations. In fact, siting inventories in locations of reduced exposure appears more imperative in military settings where disruptions might drastically increase the closure time of personnel and equipment on objectives. Such delays often lead to inadequate response times and ultimately result in decreased combat effectiveness against enemy actions. Due to these circumstances, determining the location of contingency equipment with consideration of supply chain disruption exposure is exceedingly critical to mitigate logistics delays. If one can position inventories to effectively minimize downtime resulting from external events, assets can be delivered to the right place at the right time to the right customer to successfully carry out combat or humanitarian operations. This article presents a case study that offers both insight and instruction for determining the placement of contingency equipment in support of the full range of military operations (ROMO).

Background & Problem Statement

The United States Air Force (USAF) Civil Engineer (CE) community maintains contingency equipment required for the execution of military operations in austere environments. The equipment includes resources needed for the construction, maintenance, and repair of infrastructure vital to the support and sustainability of deployed personnel. To effectively transfer the assets into overseas theater locations, the CE community bundles equipment into Unit Type Codes (UTCs) to create modular, scalable packages that can be tailored to meet mission sets of variable scope. Currently, the UTCs are dispersed throughout the continental United States (CONUS) at various USAF installations.

In October of 2012, the Air Force Civil Engineer Center (AFCEC) released a study concerning the current posture of equipment UTCs maintained by the CE community. The results cite inconsistencies in handling, tracking, and capability reporting due to the geographical separation of equipment; in addition, the study documents system redundancies that create unneeded waste (AFCEC, 2012). Furthermore, the dispersed posture requires several points of contact to transfer UTCs within the CONUS prior to overseas shipment; the excess handling, coordination, and movement creates a slow, burdensome deployment process that drives up cost and enables delay (Overstreet, 2004). As a result of the current system inadequacies, the CE community began to review alternative options for equipment UTC positioning within the CONUS. The investigation included several military studies suggesting the consolidation and forward placement of inventories results in cost savings and substantial efficiencies over a dispersed posture (Overstreet, 2004; Skipper, Bell, Cunningham, and Mattioda, 2010). Due to these findings, the AFCEC proposed three courses of action (COAs) for further analysis:

1. Maintain current dispersed posture
2. Establish one CONUS holding location near a Port of Embarkation (POE)
3. Establish two CONUS holding locations, one on the west and east coast near a POE

Each alternative to the status quo includes the consolidation of 384 equipment UTCs, maintained by 163 different CE units, and positioned at 116 separate locations within the CONUS. Table 1 provides the candidate sites proposed as holding locations by the AFCEC.

Table 1: Candidate Consolidation Locations

East Coast	West Coast
Charleston AFB	March ARB
Dover AFB	Travis AFB
McGuire AFB	McChord AFB
Westover ARB	-

(AFCEC, personal communication, January, 2013)

Given the problem's inherent complexity, the CE community enlisted the help of the Air Force Institute of Technology (AFIT) to analyze the alternative options for equipment UTC posture within the CONUS while considering exposure to disruptive events. Specifically, the analysis determines two key decision-making criteria:

1. Report the probability and severity of an adverse weather event occurring at <u>any</u> location for each alternative posturing option
2. Report the probability and severity of an adverse weather event occurring at <u>all</u> locations simultaneously for each alternative posturing option

The two decision criteria address the how and where to place contingency equipment to achieve minimal levels of exposure to disruptive events, namely adverse weather. For the purposes of this study, the term "adverse weather" is inclusive of natural disasters classified as climatological, meteorological, hydrological, or geophysical.

Literature Review

In order to understand the full context of the problem, an extensive literature review was conducted concerning supply chain disruptions and available mitigation methods. Each ensuing section presents research completed in subject areas pertinent to the military case study. The initial subject area reviews the impact of supply chain disruptions, indicating why such events should be of serious concern; successive sections examine aspects of disruption risk classes, disruption risk agents, mitigation strategies, and risk quantification. Furthermore, the literature review justifies narrowing the scope to potential disruptions caused by adverse weather events.

Impact of Disruptions

In its most general sense, supply chain disruptions are unexpected episodes resulting in the interruption of materials transitioning through the supply chain (Craighead, Blackhurst, Rungtusanatham, and Handfield, 2007; Behdani *et al.*, 2012). Often, such disruptions lead to significant exposure of firms to operational and financial losses. For instance, Capgemini (2012) reported results of the BCI research over the period of 2009-2011, suggesting economic losses from supply chain disruptions increased $350 billion, marking an escalation of 465% during that time. The substantial cost complements findings of Hendricks and Singhal (2005), who indicate organizations experiencing a disruption suffer up to a 40% loss in stock returns compared to their peers; the authors also report an average drop of 107% in operating income, a 7% lower sales growth, and an 11% cost growth in the year leading to the disruption. Furthermore, a compilation of BCI Supply Chain Resilience surveys reveals 76% of respondents experienced annual disruptions (BCI, 2012a; BCI, 2011; BCI, 2010; BCI, 2009). Within context of the military problem, general performance displaces profitability where senior leaders express more concern with delivering personnel and equipment at the right place and time to combat enemy actions (CJCS, 1996; CJCS, 2000). As such, it is important to note recovery of performance following a disruption can span a week up to two years depending upon the event severity and organizational readiness (Hendricks and Singhal, 2005; Capgemini, 2012; BCI, 2012b). Given the degradation of both operational and financial performance resulting from supply chain disruptions and the considerable number of firms reporting incidents, the CE community appears justified to consider supply chain disruptions when determining structure and placement of critical inventory holdings.

Classes of Disruption Risk

Throughout the literature, researchers classify disruption risk to facilitate risk identification (Wu, Blackhurst, and Chidambaram, 2006; Stecke and Kumar, 2009; Behdani *et al.*, 2012). However, there appears to be no standard system for classification. For instance, Christopher and Peck (2004) establish a location based system with categories of 1) internal to the firm, 2) external to the firm but internal to the supply chain network, and 3) external to the network. Several subsequent authors aligned and simplified the classification to include only internal and external risks (Goh, Lim, and Meng, 2007; Olson and Wu, 2010; Thun and Hoenig, 2011). Generally, internal risk refers to issues arising from equipment failure, information technology interruptions, and problems coordinating supply and demand; whereas, external risk refers to issues arising outside organizational span of control such as a terrorist attack, adverse weather, labor strikes, epidemic, and political instability (Kleindorfer and Saad, 2005; Olson and Wu; 2010). In contrast, other authors opt for a scale based system with categories of 1) high likelihood, low impact and 2) low likelihood, high impact (Oke and Gopalakrishnan, 2009; Knemeyer, Zinn, and Eroglu, 2009). In most cases, internal disruptions align with the former and external disruptions with the latter of the scale based categories. Additionally, the literature offers more expansive classifications to include but not limited to disruption, delay, operational, and intellectual property risk (Chopra and Sodhi, 2004; Tang, 2006). For consistency purposes, this article adopts the internal versus external taxonomy; furthermore, the study focuses directly on external risk due to its commonly uncontrollable nature causing it to be more difficult to manage relative to internal risks (Wu *et al.*, 2006; Trkman and McCormack, 2009). Moreover, disruptions arising from internal risk agents are less affected by a geographical location decision which is the primary purpose for research supporting the military case study.

External Risk Agents

The supply chain disruption literature identifies a vast number of external risk agents. However, such agents can normally be categorized as continuous or discrete events (Trkman and McCormack, 2009). Table 2 provides a list of prominently cited external risk agents aligned with the aforementioned categories. While all of the identified external risk agents certainly contribute to the overall risk exposure of a particular firm, those categorized as continuous maintain less relevance to the military case study at hand. For example, all potential locations and supply structures are subject to similar technological developments, price volatility, inflation rates, and so forth; therefore, analysis of such variables does not provide any conclusive resolution to the proposed research objective: how and where to place contingency equipment to achieve minimal levels of exposure to disruptive events. As a result, the study only considers discrete events further. Comparable to Wu *et al.* (2006), each prominent risk agent is vetted through available literature to determine applicability to the military case study hereafter.

Table 2: Prominent External Risk Agents

Agent Categories	External Risk Agents	Trkman and McCormack (2009)	Stecke and Kumar (2009)	Olson and Wu (2010)	Thun and Hoenig (2011)
Continuous	Technology Developments	X		X	X
	Price Volatility	X		X	X
	Demand Volatility	X		X	
	Inflation	X			
	Exchange Rate Risk	X		X	
	CPI	X		X	
Discrete	Adverse Weather	X	X	X	X
	Labor Strike	X	X	X	X
	Epidemics	X	X		
	Terrorist Attack	X	X	X	X
	War		X	X	X
	Accidents	X	X	X	X
	Customs & Regulations	X	X	X	X

Adverse Weather

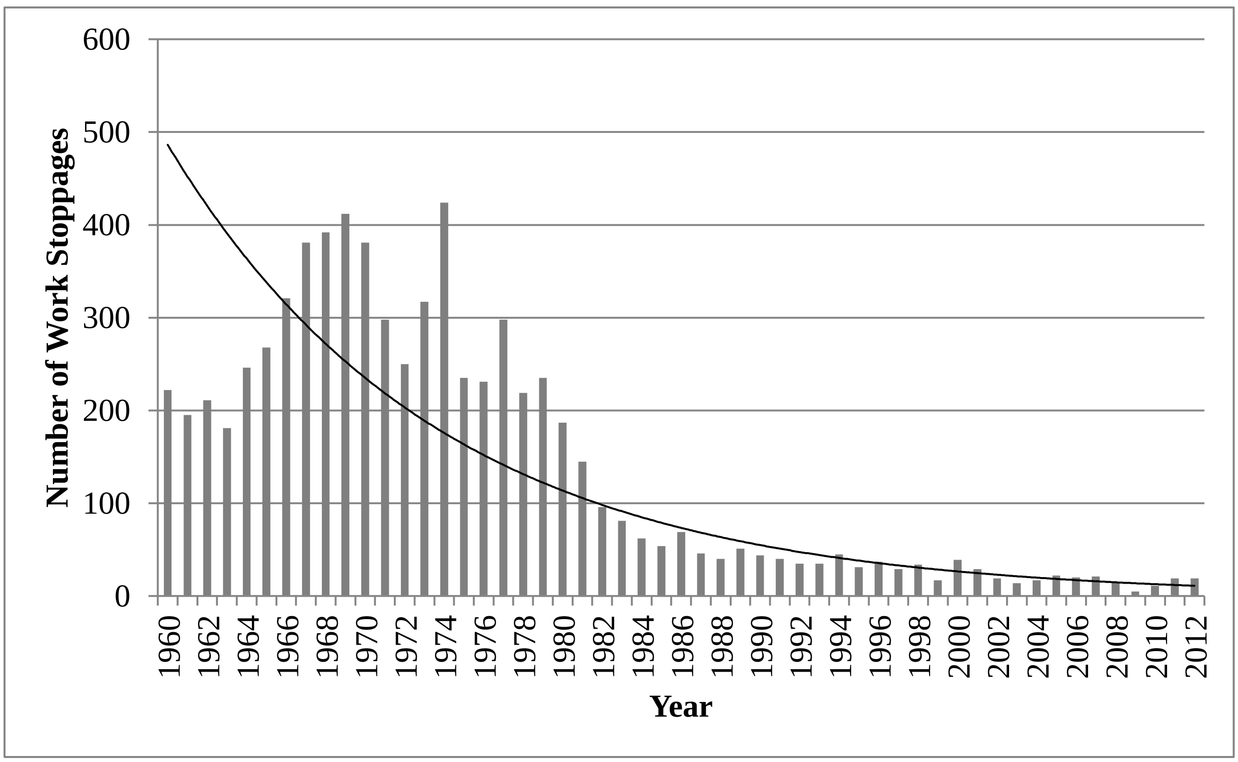
Adverse weather continues to play a critical role in supply chain disruptions as evidenced by recent natural disasters Super Storm Sandy and Hurricane Katrina, whose combined economic losses surpassed $150 billion and rendered sizeable coastline areas inaccessible and businesses inoperable (Knabb, Rhome, and Brown, 2005; Blake *et al.*, 2012). In fact, Hurricane Katrina caused severe losses or capability suspensions to ports throughout the Gulf Coast that support cargo services for 28 states and provide $37 billion to the United States economy (Skipper, Hanna, and Gibson, 2010). While the reported damages prove to be extensive, estimated figures are lower than actually realized considering totals do not account for lost business revenue during response to and recovery after the occurrence of a natural disaster. Provided the substantial impact of such events, it comes as no surprise reports by Capgemini (2012) and the BCI (2011) identify adverse weather as the single largest contributor to supply chain disruptions. To compound the issue further, several authors note the frequency and severity of adverse weather events are increasing with time (Dore, 2003; Dilley *et al.*, 2005; Cutter and Emrich, 2005; Stecke and Kumar, 2009). Moreover, occurrences appear to be spatially related, in that certain geographical locations exhibit more susceptibility to adverse weather events and their resulting disruptions than others (Stecke and Kumar, 2009). For instance, the United States experienced a significant number of natural disasters during the period 1960-2009 with 951 recorded events, while other comparably sized countries such as Russia and Canada endured only 283 and 145, respectively (EM-DAT, 2013).

Given this information, it appears adverse weather events must be considered when determining supply chain structure and inventory holding locations; especially since military installations and personnel exhibit the same vulnerabilities in such situations as their private sector counterparts. In other words, adverse weather events are indiscriminate and hold the same potential for disruption of military and civilian supply chains. As a result, the article considers the risk agent further in the military case study.

Labor Strike

Labor strikes, another supply chain disruption risk agent, can cause detrimental consequences to an organization’s productivity, operability, and profitability (Trkman and McCormack, 2009; Stecke and Kumar, 2009; Olson and Wu, 2010; Thun and Hoenig, 2011). In 2002, United States west coast ports were rendered inoperable due to the lockout of 10,500 longshoremen over an eleven day period; estimates indicate the work stoppage cost the national economy over $10 billion prior to President George W. Bush's invoking the Taft-Hartley Act to resume port activity (Sanger and Greenhouse, 2002; Craighead *et al.*, 2007). Throughout the last fifty years, it appears employees and employers have acknowledged the economic impact of work stoppages on themselves and their firms; thus, labor disputes have decreased over time (Belser, 2012; Bureau of Labor Statistics, 2013). Figure 1 illustrates the number of work stoppages by year from 1960-2009.

Figure 1. United States Work Stoppages, 1960-2009



(Bureau of Labor Statistics, 2013)

Even as the frequency of labor strikes erodes, the economic consequences stemming from such disruptions should certainly be accounted for in a firm's operational contingency plan. However, when considering the military case study, the risk agent does not pose a substantial threat for two reasons: 1) the CE equipment UTCs are primarily handled by active duty military personnel who are prohibited from striking under the Uniformed Code of Military Justice, and 2) should the strike originate outside of the military and present a threat to national security, the President of the United States may invoke the Taft-Hartley Act to end the strike. Due to these circumstances, the article does not consider the risk agent further in the military case study.

Epidemics

Researchers mention epidemics and pandemics throughout the supply chain literature regarding their potential to cause disruptions; however, few authors, if any at all, expand beyond providing a concise example (Sheffi and Rice Jr., 2005; Wagner and Bode, 2006; Oke and Gopalakrishnan, 2009; Stecke and Kumar, 2009). Perhaps the most cited instance is the 2003 SARS outbreak which reportedly inflicted a $40 billion loss to the global economy (Lee and McKibbin, 2004; Sheffi and Rice Jr., 2005; Tang, 2006; Stecke and Kumar, 2009). However, like other disruptive risk agents, epidemics do not equally affect all countries. For instance, during the period 1960-2009 over 1,200 epidemics were recorded globally with only five occurring in the United States; whereas, others experienced as many as 63 total events (EM-DAT, 2013). Data also indicates the United States remains below the global average in terms of occurrences and deaths as indicated in Table 3.

Table 3. Global Versus United States Epidemic Statistical Data, 1960-2009

		Global	
Category	**United States**	**Average**	**Total**
Occurrences	5	8.34	1,201
Deaths	317	1,482.99	213,550

(EM-DAT, 2013)

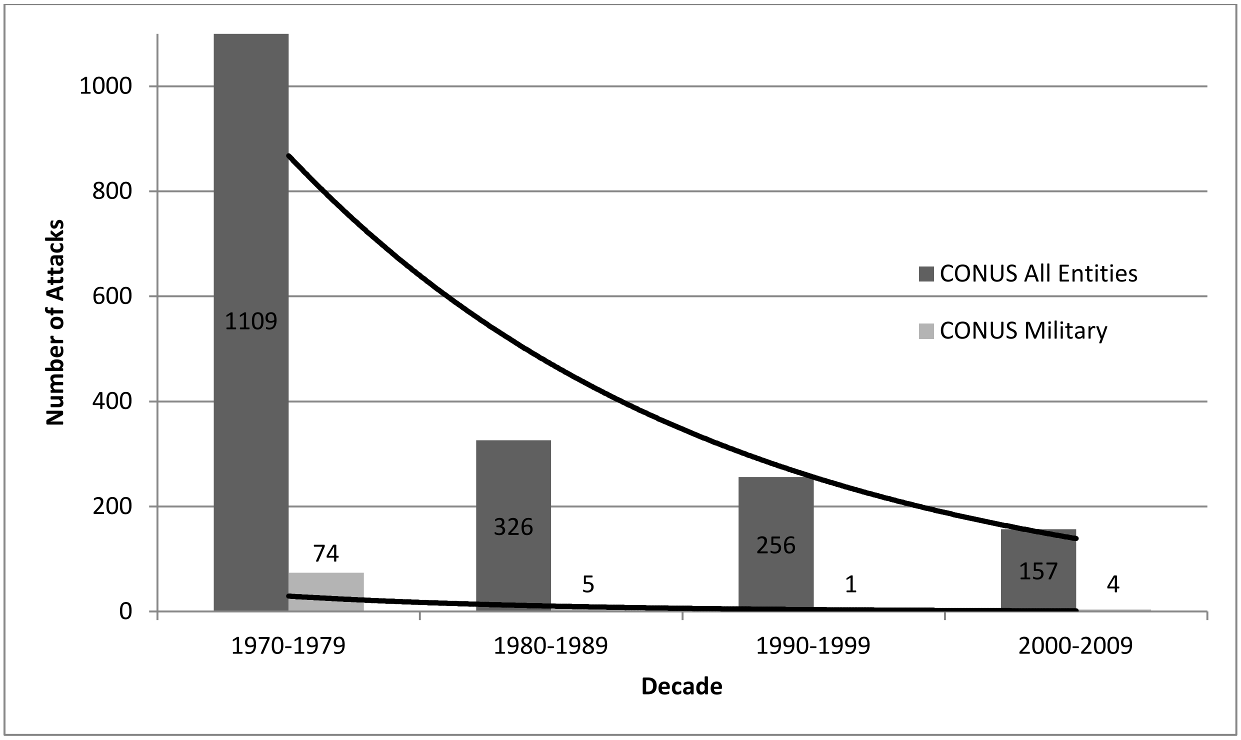
While the impact of epidemics on supply chains is very real, the risk agent proves to be a subsidiary threat for the military case study. First, the frequency of epidemics appears much lower than other risk agents (*e.g.* 17,351 natural disasters versus 1,201 epidemics) and the impact is often negligible; obviously, acute exceptions due occur. Second, the consolidation points considered in this study for equipment inventory will be located within the CONUS offering a location of reduced threat potential. Finally, government regulations require the United States armed forces to obtain vaccinations intended to protect against possible pandemic threats (Department of the Air Force, 1995). Considering this information, the article does not consider this risk agent further in the military case study.

Terrorist Attack

Several authors contend the importance directed towards mitigating supply chain disruptions increased substantially following the terror attacks of 9/11 (Lee and Hancock, 2005; Hale and Moberg, 2005; Dani, 2009). The renewed interest is rightfully founded considering estimates peg economic losses attributed to the event approached $2 trillion, with production losses of goods and services accounting for $100 billion (IAGS, 2004). Sheffi and Rice Jr. (2005) provide a more localized example resulting from 9/11, where Ford Motor Company's fourth quarter output decreased by 13% due to delays in component deliveries as trucks were stopped at the borders of Canada and Mexico. Due to such instances, United States government and business entities expended extensive amounts of resources on enhancing security; the government alone spent $29 billion from 2001-2011 (Stein, 2011).

Examining data from the Global Terrorism Database (GTD) (2012), there appears to be no global trend regarding the frequency of attacks; however, the number of events occurring within the United States has dropped considerably. Figure 2 illustrates the decreasing trend of terror attacks over the period 1970-2009.

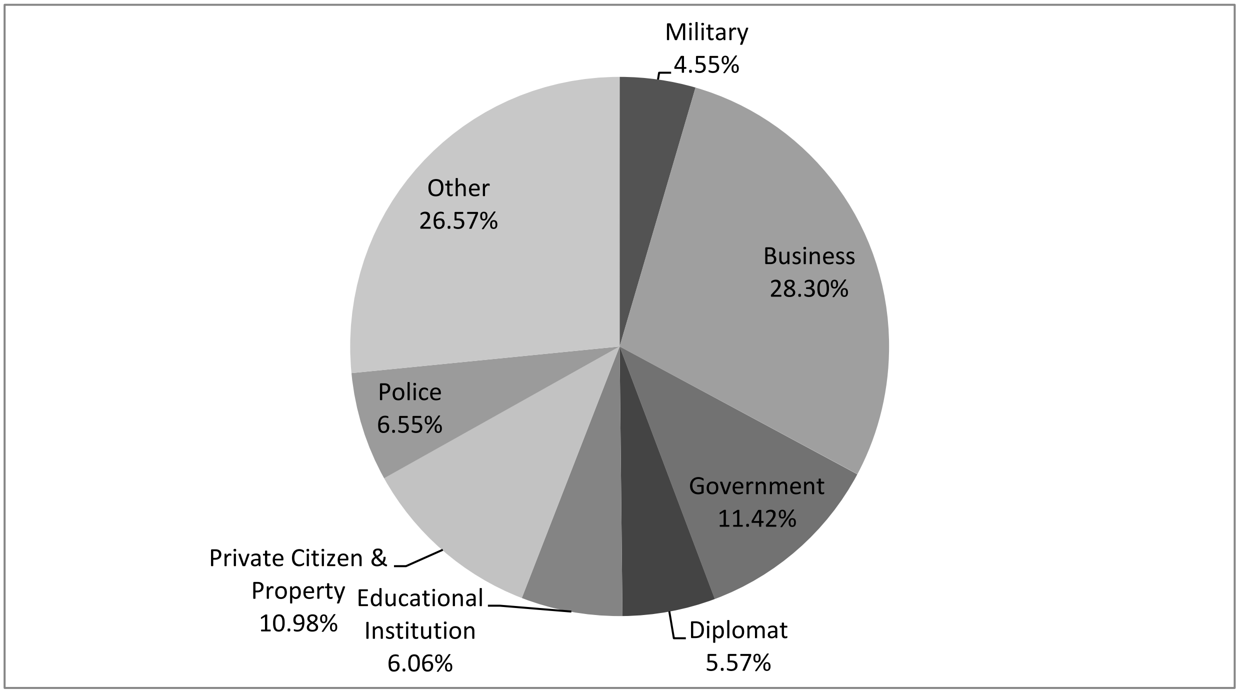
Figure 2. Number of Terror Attacks Occurring in United States, 1970-2009



(GTD, 2012)

During the same period, 2.67% of world-wide attacks targeted the CONUS, with those directed toward businesses and the military at 28.30% and 4.55%, respectively. Removing 1970-1979 from the data set, only 1.21% of all global terror events occur within the United States, with 1.35% of those directed towards the military (GTD, 2012). Figure 3 provides of breakdown of targeted entities from 1970-2009. Further scrutiny of the data indicates a large distribution of terror attacks occur in densely populated urban areas; however, the same spatial trend does not hold for military targets, where no discernible pattern readily presents itself (GTD, 2012; START, 2012). In fact, the GTD (2012) reveals, with exception to two cases, no military installation experienced more than one attack.

Figure 3. Breakdown of Terror Targets within United States, 1970-2009



(GTD, 2012)

Coupling the relatively low frequency of attacks, lack of spatial trend for military targets, and the numerous countermeasures in place on USAF installations, the article does <u>not</u> consider acts of terror further in the military case study. Such a decision is not intended to detract from the importance of terror events, but given the extensive antiterrorism and force protection standards employed by each USAF installation, the inclusion of such events does not provide any indication of which geographical locations are better suited to host critical inventories. It should be noted the rendered judgment bases itself on the assumption each candidate location selected for maintaining CE equipment UTCs complies with required antiterrorism and force protection regulations outlined by Federal, Department of Defense (DoD), and USAF agencies (DoD, 2012; Department of the Air Force, 2012).

War

War, regularly mentioned in the context of political instability, is cited in the majority of supply chain disruption literature as a potential risk agent (Stecke and Kumar, 2009; Olson and Wu, 2010; Thun and Hoenig, 2011). Similar to other low likelihood, high impact disruptions, war maintains the potential to catastrophically interrupt regional supply chains; the degraded capability of the affected regions often propagates globally. One localized example is demonstrated by Pakistan's closure of critical supply routes along its western border in November of 2007, a retaliatory action due to the death of 24 Pakistani soldiers from a United States drone strike (Keck, 2012). The heavily used crossings provided coalition forces the ability to resupply ongoing war efforts. Keck (2012), relaying an Associated Press report, indicates the closure cost the United States an additional $87 million per month; increasing the price tag of transporting supplies into Afghanistan by 600%.

Undoubtedly, the disruption of supply chains due to war proves costly; however, the article does not consider the risk agent further in the military case study due to all candidate inventory holding locations being within CONUS. To elaborate, the CE equipment UTC supply bases considered here are located in the United States; therefore, all locations are subject to the same disruptions inflicted by overseas wars and the analysis of such events does not provide any indication how and where inventories should be placed within CONUS.

Accidents

The supply chain literature details many examples of accidents causing logistics interruptions. Several authors detail the 2003 blackout of the northeastern United States which resulted in an estimated economic loss of $6 billion (ELCON, 2004; Kleindorfer and Saad, 2005; Stecke and Kumar, 2009). The Electricity Consumers Resource Council (ELCON) (2004) provides numerous industry specific disruptions caused by the 2003 black out; for instance, DaimlerChrysler AG lost production at 14 of 31 plants within the United States and was forced to scrap over 10,000 vehicles. Other notable accidents include the British Petroleum (BP) oil spill, Exxon Valdez oil spill, Three Mile Island nuclear explosion, and Bhopal.

Man-made accidents exact a weighty toll on people, the environment, and economy; however, even with its significance, the article does not consider the risk agent further in the military case study. A couple reasons present themselves for such a decision: 1) USAF installations maintain several fallback contingencies should a number of different type accidents occur which affect their operations (*e.g.* backup generators, spill response, fire response), and 2) USAF installations maintain, practice, and execute an emergency management program in accordance with mandated guidance. Accordingly, analysis of accidents would provide no substantive conclusion to further the stated research objective.

Customs & Regulations

The supply chain literature provided relatively few examples regarding logistics interruptions caused by various customs and regulations; however, many researchers mention customs and regulations as potential disruptive risk agents (Oke and Gopalakrishnan, 2009; Trkman and McCormack, 2009; Olson and Wu, 2010; Thun and Hoenig, 2011). Recapping a study by the Aberdeen Group, Camerinelli (2008) indicates failing to fully understand and comply with trade regulations can lead to several unfavorable outcomes, one of those being customs clearance delays. Table 4 compiles a list of additional adverse effects resulting from trade regulation non-compliance.

Table 4. Unfavorable Outcomes of Trade Regulation Non-Compliance

Increased Landed Costs	Higher Duty Payments
Higher Regulatory Penalties	Erroneous Declarations
Increased Cash-to-Cash Cycles	Discrepant Credit Charges

(Camerinelli, 2008)

Provided the potential for delay, organizations participating in the global supply chain must pay heightened attention to customs and regulations to avoid lengthy and recurring disruptions. Considering the military case study, the implications of 'frustrating' cargo can be devastating to deployed operations, as shipments to critical areas can be held up for extended periods of time without proper documentation. However, the risk agent does not further any conclusion on supply chain structure or location. For instance, all locations are within the CONUS; therefore, subject to the same customs and regulations from departure to arrival within the area of operations. As a result, study does not provide additional consideration of such events.

From the review of aforementioned risk agents, the importance a firm must place on such events in order to effectively mitigate possible supply chain disruptions readily reveals itself. Also, it becomes apparent for those reviewing possible threats to delineate which risk agents are relevant for making certain decisions. With context to the military case study, we determined adverse weather events play a critical role in inventory storage location and structure decisions; therefore, the article scrutinizes the risk agent further to accomplish the stated research objective. Table 5 provides a summary of the risk agents reviewed, whether they are applied to the military case study, and the justification for inclusion or exclusion.

Table 5. Summary of Risk Agent Review

Disruption Risk Agent	Utilized for Analysis		Justification
	Yes	No	
Adverse Weather	X		1. Exhibits a strong spatially related trend 2. Occurs most frequently of discrete risk agents
Labor Strike		X	1. Military personnel prohibited from striking 2. President can execute Taft-Hartley Act
Epidemics		X	1. Frequency much lower than other risk agents 2. US based equipment at reduced threat location 3. Military personnel receive required vaccinations
Terrorist Attack		X	1. No significant spatial trend exhibited 2. Military maintains contingency response plans 3. Military executes antiterrorism countermeasures
War		X	1. US based equipment at reduced threat location 2. All candidate locations subject to same overseas war disruptions
Accidents		X	1. Military maintains several fallback contingencies 2. Military maintains, practices, and executes emergency management program
Customs & Regulations		X	1. No spatial trend identified 2. All candidate locations subject to same customs and regulations disruptions

Risk Mitigation Strategies

Relevant literature often defines risk through the development of two variables: the probability of an event occurring and the severity or consequence of such an occurrence (Kaplan, 1997; Dani, 2009; Knemeyer *et al.*, 2009; Behdani *et al.*, 2012). Equation 1 provides a mathematical representation of risk.

$$Risk = (Probability\ of\ Event\ Occurence)\ x\ (Severity) \qquad (1)$$

To combat the growing risk of supply chain disruptions, firms, practitioners, and researchers developed mitigation strategies aimed at reducing the probability, severity, or both aspects of risk. Behdani *et al.* (2012) suggests such strategies can be categorized as risk acceptance, reduction, avoidance, and transfer.

Risk Acceptance

The strategy of acceptance targets neither of the two risk variables. Organizations often pursue this strategy when the level of risk is below an established threshold, the cost of implementing countermeasures outweighs the cost of disruption, or no clear avenue of intervention can be identified (Tomlin, 2006; Knemeyer *et al.*, 2009; Behdani *et al.*, 2012; Chakravarty, 2013). Tomlin (2006) explains firms often adopt acceptance as the default strategy even if the situation demands otherwise. Given the passive nature of acceptance, supply chain disruption literature pays little attention to the subject; instead, researchers focus efforts toward active actions.

Risk Reduction

Reduction strategies focus on targeting one of the two risk variables, either probability or severity. By minimizing one of the variables, the overall level of risk begins converging to an acceptable threshold. Behdani *et al.* (2012) suggests classifying reduction mitigation approaches based on underlying characteristics such as flexibility, redundancy, control, and cooperation.

Flexibility can refer to countermeasures directed at the supply base, transportation, product configuration, or manufacturing process (Behdani *et al.*, 2012). The use of multiple suppliers is a frequently suggested course of action to reduce the severity of a supply chain disruption (Tang, 2006; Tomlin, 2006; Stecke and Kumar, 2009; Thun and Hoenig, 2009). Such a strategy allows organizations to shift unfulfilled orders to another suppliers should a disruption occur at a different source. Of course, this assumes all suppliers maintain additional capacity to handle increased demand. Contingency planning offers another option that facilitates organizational flexibility in response to and recovery after a supply chain disruption (Hall, Skipper, and Hanna, 2010). Skipper and Hanna (2009) indicate the implementation of such planning helps minimize potential loss to company assets and serviceability. Other courses of action cited include postponement and utilizing multiple avenues of transport (Tang, 2006; Oke and Gopalakrishnan, 2009; Stecke and Kumar, 2009).

Redundancy often incorporates actions directed at inventory, suppliers, or capacity (Behdani *et al.*, 2012). Chopra and Sodhi (2004) suggest maintaining extra inventory creates a buffer should part of the supply chain experience a disruption. Stecke and Kumar (2009) identify employment of back-up suppliers as a possibility, where a firm reserves capacity at an undisrupted supplier should the need arise. While the countermeasures may prove effective in mitigating disruptions, the implementation of redundancy proves to be costly in most cases (Sheffi, 2001; Chopra and Sodhi, 2004).

Control concentrates on management aspects that affect a firm's risk exposure. Behdani *et al.* (2012) identifies management actions related to improving security, shifting demand, screening suppliers, performance contracting, and contingency training. Stecke and Kumar (2009) contend promoting specific products based on availability of components is a viable control strategy aimed at shifting or managing demand. Christopher and Peck (2004) offer another control measure by selecting suppliers whom exhibit the ability to cope well with disruptions. Essentially, such strategies key on decisions that can be better managed or controlled through a higher degree of supervision (Behdani *et al.*, 2012).

Cooperation comprises decisions which involve all partners throughout the supply chain (Behdani *et al.*, 2012). Such collaboration can be aimed at developing joint contingency plans to mitigate or recover from a disruption, sharing reserve inventory, or simply advocating for better communication networks between partners (Christopher and Peck, 2006; Tang, 2006; Stecke and Kumar, 2009).

Risk Transfer

Risk transfer is intended to reduce the severity of a disruption by shifting the consequence to a third party. The primary method for executing this strategy is through the procurement of insurance (Tomlin, 2006; Knemeyer *et al.*, 2009; Stecke and Kumar, 2009). Stecke and Kumar (2009) identify coverage often includes losses in revenue or assets resulting from disruption. Tomlin (2006) provides an example where Palm Incorporated received $6.4 million to cover losses from a supplier's factory fire. In any case, the transfer of risk to a third party proves to be a viable method for hedging disruption losses.

Risk Avoidance

Avoidance strategies target both variables (probability and severity) contributing to risk simultaneously. Kleindorfer and Saad (2005) indicate such a strategy should precede reduction considerations. One such method for avoiding risk is the selection of safe locations for a firm's operations or suppliers (Stecke and Kumar, 2009; Thun and Hoenig, 2011). Other proposed strategies include entering secure markets or focusing on products with constant demand (Manuj and Mentzer, 2008; Thun and Hoenig, 2011).

In many cases, risk avoidance coincides with risk pooling strategies, where risk pooling reduces the variability and uncertainty in demand by aggregating its source across locations, products, or time (Simchi-Levi, 2003). Pooling risk in this manner targets both the probability and severity of a supply chain disruption by reducing and spreading risk exposure across customers or markets. For example, consolidating inventory allows the location to consistently service the aggregate demand with reduced stock levels, thus if low demand materializes from one customer it can be typically be offset by servicing another (Chopra and Sodhi, 2004). The same proves true when considering the design of goods such that companies manufacture common components to perform in different products (Tang, 2006).

Considering all of the mitigation methods presented within the supply chain disruption literature, risk avoidance proves to be the most applicable to the military case study. By selecting a safe supply location and structure, both the probability and severity risk variables are reduced; thereby, minimizing the opportunity of supply chain disruptions as much as possible. While the targeted risk agent and associated mitigation strategy have been identified, the appropriate method for quantifying risk and subsequently furthering the stated research objective is discussed hereafter in both the Risk Quantification and Methodology sections.

Risk Quantification

Behdani *et al.* (2012) explains most supply chain literature aligns with the following steps toward treating disruptions risks: 1) Risk identification, 2) Risk Quantification, and 3) Risk Mitigation. However, the military case study lent itself directly toward identifying risk agents and selecting a mitigation strategy prior to risk quantification. To elaborate, the problem framed itself as a location based decision; therefore, it made sense to identify the risk agents and strategies upfront that most effect such determinations. Now, a method for quantifying the risk for each location and structure must be adopted.

Throughout the literature, there exist several methods for determining both the probability and severity of an event. Dani (2009) suggests the use of data mining and Failure Mode Effect Analysis (FMEA). Data mining, for the most part, includes the examination of historical data to determine parameter estimates for future prediction. FMEA investigates the effect of component failure within a particular system. For instance, if a particular event disrupts a supplier, what resulting probability and impact for system failure materialize? Wu *et al.* (2006)

utilizes an Analytic Hierarchy Process (AHP), where risk factors are assigned relative weights and coupled with an industry determined probability of occurrence to ascertain the impact of specific factors on the overall system. Still, others propose the use of simulation, graph theory, expert judgment, or a combination thereof (Bigun, 1995; Wilson, 2007; Wagner and Neshat, 2010; Thun and Hoenig, 2011).

In summary, managers have a multitude of methods available to solve an organization's supply chain disruption risk problems. The process for quantifying risk in the military case study relies on the suggestion of Knemeyer *et al.* (2009), where historical data can be used to determine acceptable estimates. However, the study applies a modified approach that eliminates the requirement of combining such data with expert judgment. The selected method will utilize the historical frequencies of adverse weather events to determine both the probability of occurrence and severity related to differing geographical locations and structures. The process provides managers a practical method that does not require extensive technical competence. As a result, less reliance can be placed on outside resources or human capital to resolve a firm's disruption decisions.

Methodology

Database & Adverse Weather Type Selection

Prior to beginning the risk quantification process, a database maintaining historical information on adverse weather events had to be identified and selected. In concert with that selection, the types of adverse weather events to be considered for analysis were determined. Given the study concerns itself with relatively small geographic areas (*e.g.* military installation), the Spatial Hazard Events and Losses Database for the United States (SHELDUS) was chosen due to the county-level data set. Furthermore, the database maintains a smaller threshold for recording such events which proves more conservative when reporting occurrences that hold potential for disruption. For instance, SHELDUS (2013) reports every event that causes a monetary or human loss; whereas, EM-DAT (2013) records instances that cause ten or more deaths. Certainly, EM-DAT provides data on more significantly impacting disasters, but establishing higher thresholds fails to acknowledge the fact that, “smaller weather events cause the most damage to supply chains” (Stecke and Kumar, 2009). Examining the available hazard data within SHELDUS, the study becomes limited to eighteen different adverse weather types. While the inclusion of some types proves to be intuitive or easily found in the supply chain literature, others were chosen based on their explicit reference in Air Force publications detailing flight limitations (Department of the Air Force, 2011). Out of the eighteen possible risk sources, only two were excluded from analysis. Table 6 lists all of the adverse weather types, an indication of whether or not it is used in analysis, and justification for such inclusion or exclusion.

Having determined the database and adverse weather event types, information was pulled for each respective county of the candidate base locations as well as the entire United States from 1960-2009. For each adverse weather event, the following information is recorded: hazard ID, hazard begin date, hazard end date, hazard type, county name, state name, injuries, fatalities, and damages. After importing the data from SHELDUS, it was examined to ensure the removal of all duplicate entries.

Table 6. SHELDUS Adverse Weather Types

Adverse Weather Type	Utilized for Analysis		Justification
	Yes	No	
Avalanche	X		Intuitive
Coastal	X		Intuitive
Drought		X	Not intuitive No USAF publication reference
Earthquake	X		Kleindorfer and Saad (2005)
Flooding	X		Knemeyer *et al.* (2009)
Fog	X		USAF publication reference
Hail	X		USAF publication reference
Heat		X	Not intuitive No USAF publication reference
Hurricane/Tropical Storm	X		Stecke and Kumar (2009)
Landslide	X		Intuitive
Lightning	X		USAF publication reference
Severe Storm/Thunder Storm	X		USAF publication reference
Tornado	X		Intuitive
Tsunami/Seiche	X		Stecke and Kumar (2009)
Volcano	X		Intuitive
Wildfire	X		Knemeyer *et al.* (2009)
Wind	X		USAF publication reference
Winter Weather	X		USAF publication reference

Probability Estimate

In order to develop a probability estimate for each possible inventory holding location and structure, the study adopts a frequentist perspective. In this sense, the frequency for each location is examined relative to the CONUS as demonstrated in equation 2.

$$rf_i = \frac{f_i}{n} \qquad (2)$$

Where:

rf_i = relative frequency for candidate location i to experience an adverse weather event

f_i = total number of adverse weather events experienced at candidate location i

n = total number of adverse weather events within the CONUS

The concept assumes that as $n \to \infty$, the relative frequency for each candidate location will converge to a real number, or its probability for occurrence (Gut, 2013). To investigate the claim, the relative frequency for each candidate location was plotted in one year intervals from 1960 to 2009 as seen in Figure 4. Reviewing the figure, few of the relative frequencies distinctly converge to an apparent real number; however, the relative frequencies do appear to maintain or approach some stability as most hold near certain values. The realization is expected due to the data set representing a limited time period of 50 years, or nearly 130 thousand adverse weather events, rather than a number with close proximity to infinity as Gut (2013). Furthermore, the limited span of data also allows periods with high variation from the norm to significantly skew reported relative frequency distributions (McClave, Benson, and Sincich, 2011). Figure 5 provides an example relative frequency distribution typical of each candidate location. Notice the ability of outlier years to skew the data set rightward.

Figure 4. Candidate Location Relative Frequency, 1960-2009

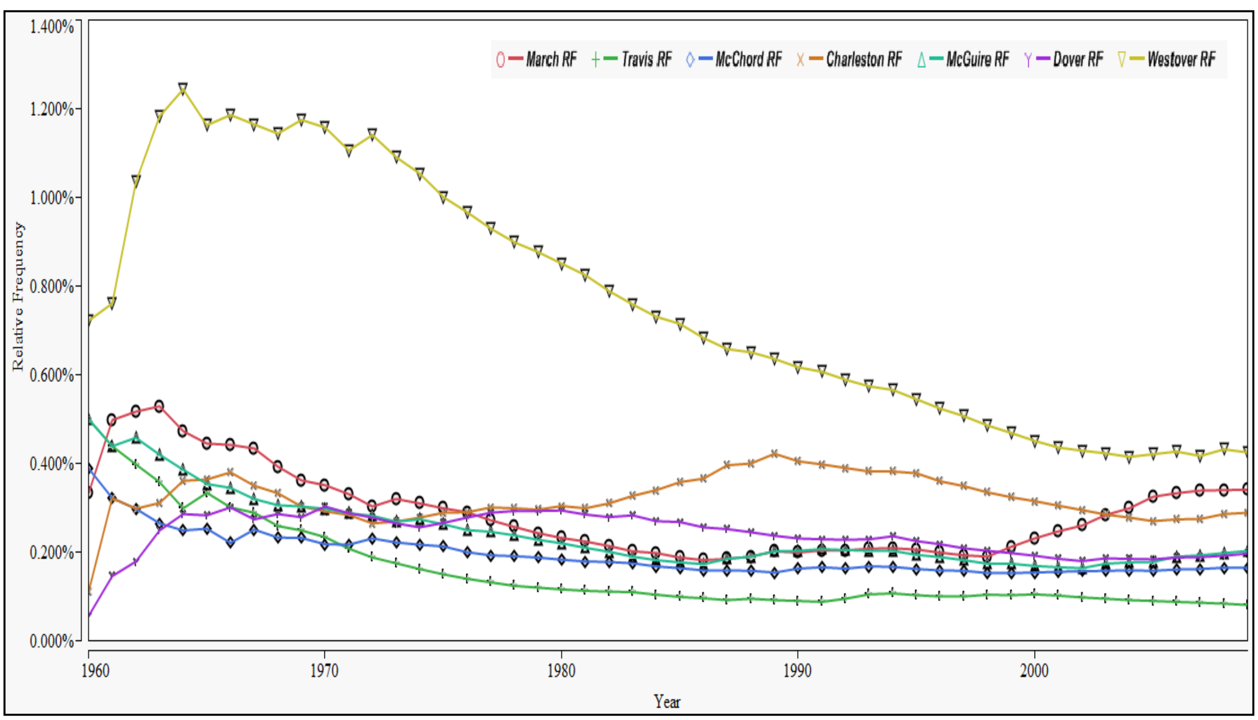
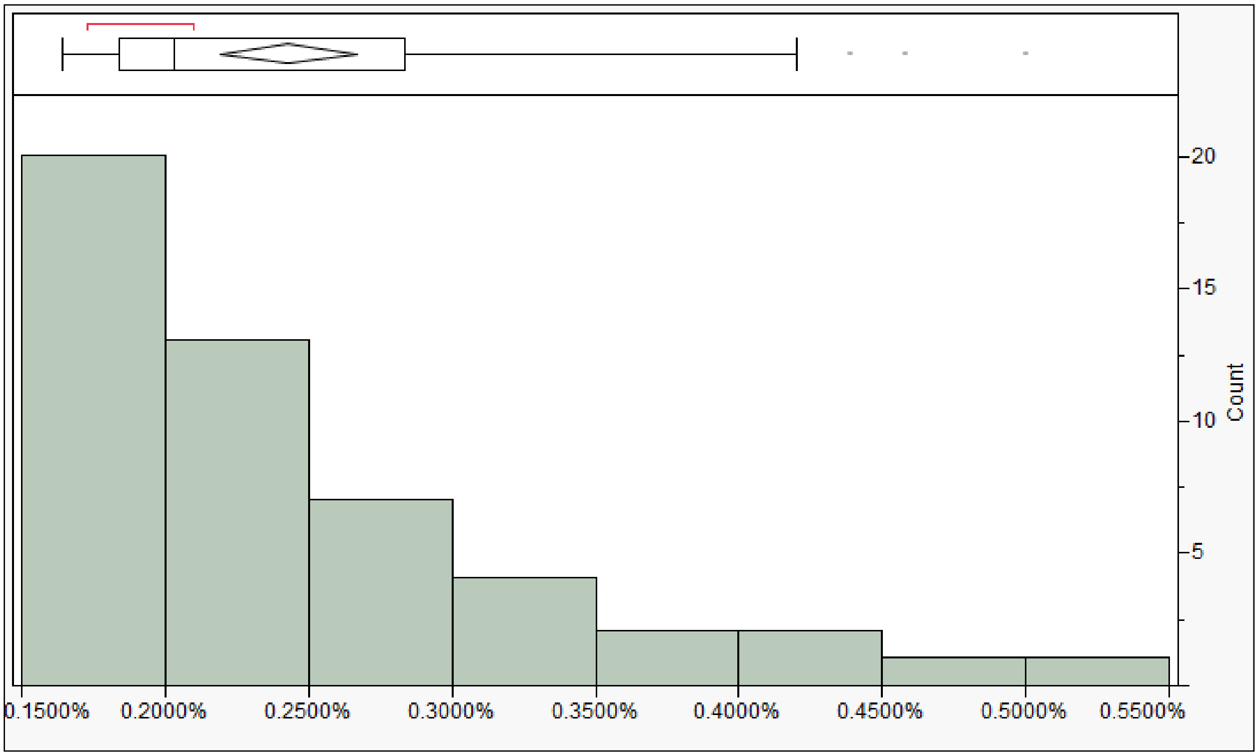


Figure 5. McGuire AFB Distribution of Relative Frequency, 1960-2009



As a result of the aforementioned limitations and ensuing issues, the study assumes the median value for each relative frequency distribution is an acceptable probability estimate. Such an assumption proves valid for a couple reasons: 1) the median is a measure of central tendency and represents a value that each relative frequency curve is likely to converge upon, and 2) the median dampens the effects of highly variable periods (*e.g.* outliers) because the value is less sensitive than the mean to relatively large and small data points (McClave, Benson, and Sincich, 2011). Table 8 and 9 of the Results section in this article report the median value for each candidate location relative frequency distribution; these values represent the probability estimate for an adverse weather event occurring at a single inventory holding location. In addition, the same table also reports the interquartile range (IQR) to indicate the scale of variation between data points not deemed to be outliers.

While the probability estimate for an adverse weather event occurring at a single candidate location has been established, the study requires another assumption to extend the concept to a dual-location supply structure. As specified by the AFCEC, in the case of two CONUS-based locations, one will be placed on the east coast and another on the west coast near a POE. Due to the substantial geographical separation, the study deemed it acceptable to assume independence between the locations. Independence is recognized when two separate events coexist and the occurrence of one event does not influence the probability that the other will or will not occur (McClave, Benson, and Sincich, 2011). In other words, the occurrence of an adverse weather event at a candidate location on the east coast will not affect the probability of an adverse weather event occurring at its location pair on the west coast. From this assumption, the probability estimate for an adverse weather event occurring at <u>any</u> (either) location for a dual-supply structure is simply the two individual probabilities added together; whereas, the probability estimate for an adverse weather event occurring at <u>all</u> (both) locations simultaneously for the same supply structure is the two individual probabilities multiplied together. Equation 3 and 4 depict these explanations mathematically.

$$P_{dual-either} = P_w + P_e \tag{3}$$

$$P_{dual-both} = P_w \times P_e \tag{4}$$

Where:

$P_{dual-either}$ = probability of an adverse weather event occurring at either east or west coast pair but not both

$P_{dual-both}$ = probability of an adverse weather event occurring at the east and west coast pair simultaneously

P_w = probability of an adverse weather event occurring at the selected west coast candidate location

P_e = probability of an adverse weather event occurring at the selected east coast candidate location

Table 8 and 9 of the Results section report the probability estimates for each east and west coast pair.

Severity Estimate

The measurement to quantify severity, or consequence, varies throughout the supply chain literature; for instance, researchers may elect to use economic losses, fatalities, injuries, total affected individuals, product throughput, a combination thereof, or some other variable altogether. However, this study utilizes an expected value for adverse weather event duration to develop the severity estimate for each geographic location. Applying the same method as previously accomplished for the probability estimate, the relative frequencies for each adverse weather type are calculated for the respective candidate locations and subsequently examined through a time series plot for convergence. Equation 5 provides a mathematical representation of the adverse weather type relative frequency calculation.

$$rf_{ji} = \frac{f_{ji}}{n_i} \tag{5}$$

Where:

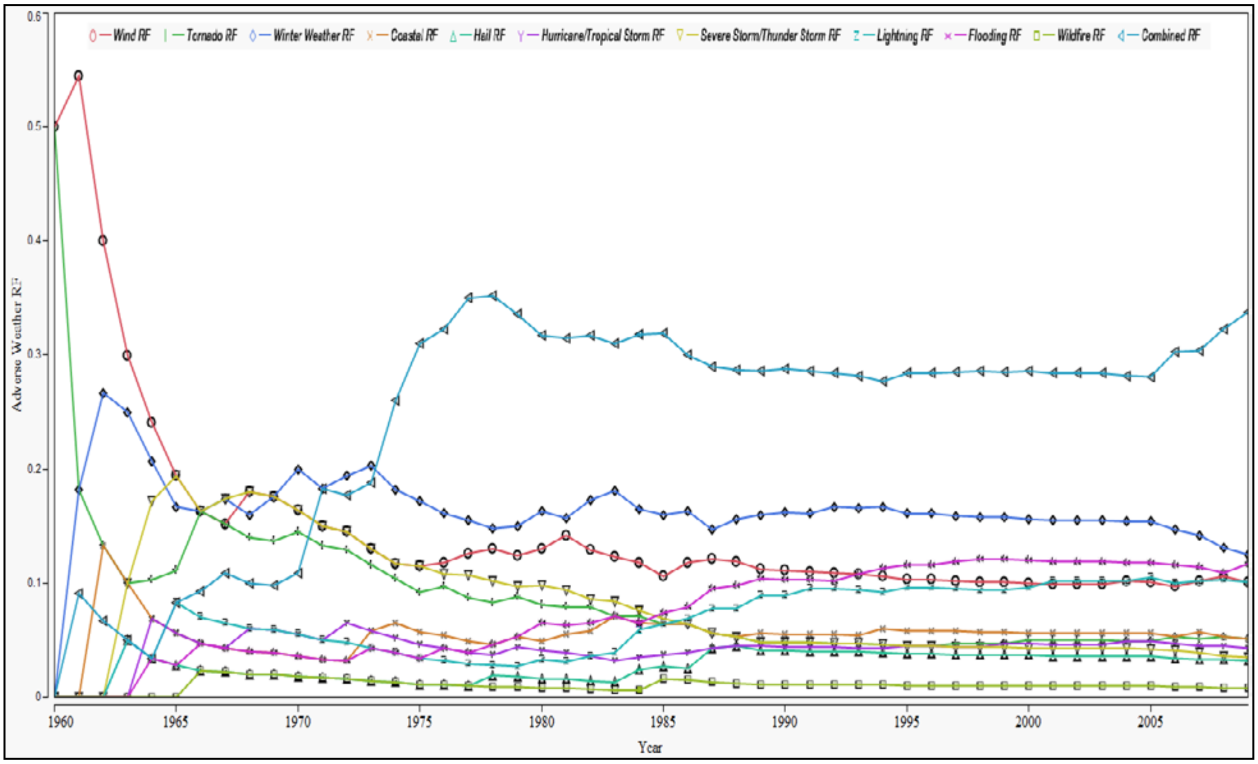
rf_{ji} = relative frequency for adverse weather type *j* occurrence at candidate location *i*

f_{ji} = frequency of adverse weather type *j* at candidate location *i*

n_i = total number of adverse weather events at candidate location *i*

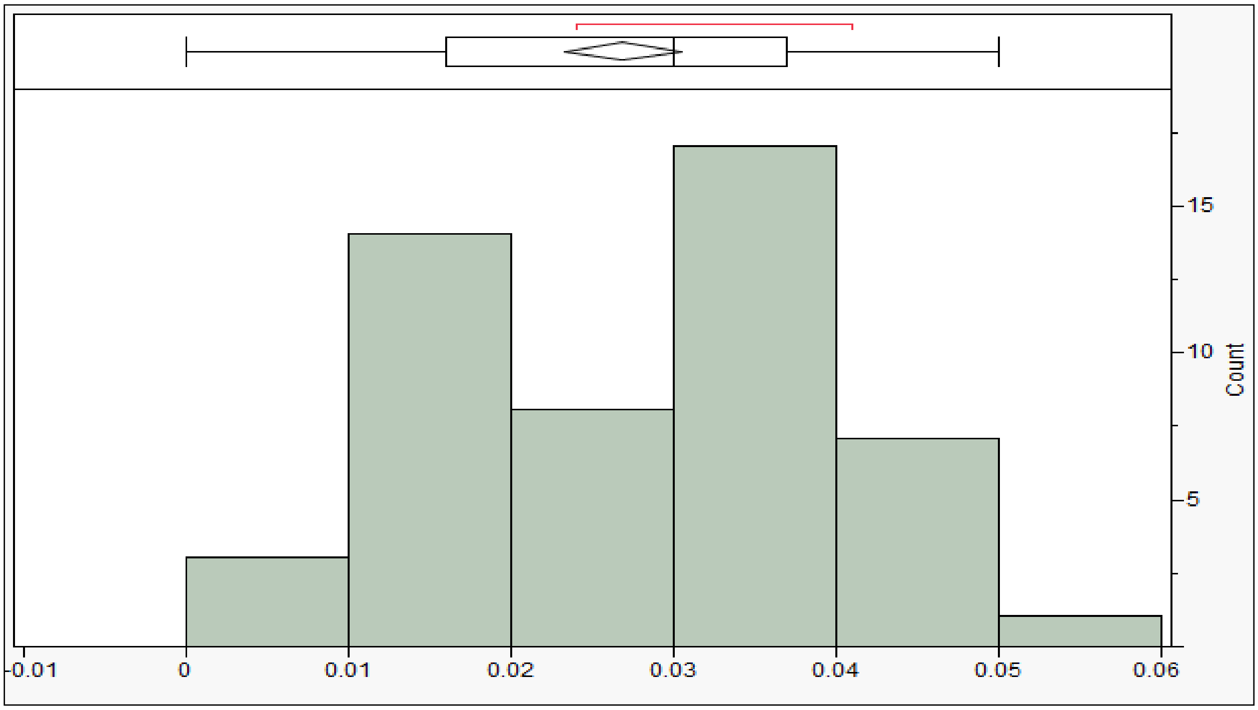
Similar to the relative frequencies previously established few of the curves definitively converge, but they do exhibit stability properties by holding relatively close to certain values. Figure 6 demonstrates an example time series of adverse weather event type relative frequencies.

Figure 6. Charleston AFB Adverse Weather Event Type Relative Frequencies, 1960-2009



Examining the distributions of each relative frequency curve over time, the plots appear to be much more normal than the skewed distributions discovered earlier. As a result, the study utilizes a mean value as the measure of central tendency to estimate the probability of a particular adverse weather event type occurring at a specified location. Figure 7 provides an example relative frequency distribution for an adverse weather event type.

Figure 7. Charleston AFB Hail Relative Frequency Distribution



Next, an average duration for each adverse weather type at the respective candidate locations is developed using the “hazard begin date” and “hazard end date” fields reported by the SHELDUS database. It should be noted events beginning and ending in the same day are assumed to last a full twenty-four hours. While this may seem contentious for some events, namely lightning, it proves to result in conservative estimates. Furthermore, it can be argued that recovery following an adverse weather event may take longer than the event itself, but the severe lack of data concerning this circumstance limited the scope of the article to include only event length. Finally, the study assumes a disruption occurs for the duration of an adverse weather event within the geographic proximity (*e.g.* county) of a candidate location.

When deriving average duration, the study examined and subsequently utilized two measures of central tendency. First, the mean value was used due to all adverse weather event duration distributions being skewed right, thus producing conservative estimates. Second, the median value was calculated to mitigate the possible effects of extreme outliers noticed within several of the skewed distributions, providing a more representative value of a typical event. The study carries both central measures throughout remaining calculations resulting in two severity estimates. Table 7 provides an example of the mean and median values for duration of an adverse weather event type at a typical base.

Table 7: Charleston AFB Adverse Weather Type Mean and Median Durations

Event Type	Duration (days)	
	Mean	Median
Wind	1.079	1.000
Tornado	1.053	1.000
Winter Weather	3.766	2.000
Coastal	1.895	1.000
Hail	1.000	1.000
Hurricane/Tropical Storm	2.188	2.000
Severe Storm/Thunder Storm	2.692	1.000
Lightning	1.000	1.000
Flooding	3.864	1.000
Wildfire	22.667	21.000
Combined*	1.598	1.000

**Combined represents events including two or more adverse weather types*

Having established the probability for occurrence and duration(s) for each adverse weather event type at the respective candidate locations, the values are combined through a sum-product to finally determine the two severity estimates for each candidate location. Equation 6 provides a mathematical representation of the expected value calculation for the severity estimate. Thus for a particular (i, j) pair,

$$\sum P_{ji} \times D_{ji} \tag{6}$$

Where:

P_{ji} = probability of adverse weather event type *j* occurring at candidate location *i*

D_{ji} = mean or median duration of adverse weather event type *j* at candidate location *i*

While the derived values provide estimates for single-location configurations, a similar expected value for severity can be calculated for dual-location structures by averaging the previously determined values of each pair. Table 8 and 9 of the Results section report severity estimates for each candidate location, to include either its east or west coast pair.

Overall Risk

Drawing attention back to the identified risk equation, where risk is the combination of both probability and severity, the objective estimates formerly described are now joined to provide an indication of the overall risk for each specified location and supply structure. Considering two measures were formed for the severity estimate (*e.g.* mean and median), the study reports two overall risk values. Subsequently, each structure and location is ranked under both estimates and then averaged to support final recommendations. Table 11 of the Results section catalogues the overall risk in ascending order of the average rank.

Results

Probability and Severity Estimates

Tables 8 and 9 present results for both the single- and dual-location probability and severity estimates.

Table 8. West Coast Probability and Severity Estimates with East Coast Pairs

March ARB

Single-Location				Dual-Location			
	Severity			Probability		Severity	
Probability	Mean	Median	East Coast Pair	Either	Both	Mean	Median
0.00266	2.139	1.339	Charleston AFB	0.00577	8.2726E-06	2.209	1.372
IQR			Dover AFB	0.00513	6.5702E-06	1.793	1.291
0.00339	75% Quartile		McGuire AFB	0.00469	5.3998E-06	1.795	1.188
0.00204	25% Quartile		Westover AFB	0.00985	1.91254E-05	1.769	1.185

Travis AFB

Single-Location				Dual-Location			
	Severity			Probability		Severity	
Probability	Mean	Median	East Coast Pair	Either	Both	Mean	Median
0.00106	3.339	1.934	Charleston AFB	0.00417	3.2966E-06	2.809	1.670
IQR			Dover AFB	0.00353	2.6182E-06	2.393	1.589
0.00193	75% Quartile		McGuire AFB	0.00309	2.1518E-06	2.395	1.486
0.00095	25% Quartile		Westover AFB	0.00825	7.6214E-06	2.369	1.483

McChord AFB

Single-Location				Dual-Location			
	Severity			Probability		Severity	
Probability	Mean	Median	East Coast Pair	Either	Both	Mean	Median
0.00168	1.958	1.403	Charleston AFB	0.00479	5.2248E-06	2.118	1.405
IQR			Dover AFB	0.00415	4.1496E-06	1.703	1.323
0.00219	75% Quartile		McGuire AFB	0.00371	3.4104E-06	1.705	1.220
0.00159	25% Quartile		Westover AFB	0.00887	1.20792E-05	1.678	1.217

Table 9: East Coast Probability and Severity Estimates with West Coast Pairs

Charleston AFB

Single-Location			Dual-Location				
	Severity						
Probability	Mean	Median		Probability		Severity	
0.00311	2.278	1.406	West Coast Pair	Either	Both	Mean	Median
IQR			March ARB	0.00577	8.2726E-06	2.209	1.372
0.00362	75% Quartile		Travis AFB	0.00417	3.2966E-06	2.809	1.670
0.00289	25% Quartile		McChord AFB	0.00479	5.2248E-06	2.118	1.405

Dover AFB

Single-Location			Dual-Location				
	Severity						
Probability	Mean	Median		Probability		Severity	
0.00247	1.447	1.244	West Coast Pair	Either	Both	Mean	Median
IQR			March ARB	0.00513	6.5702E-06	1.793	1.291
0.00280	75% Quartile		Travis AFB	0.00353	2.6182E-06	2.393	1.589
0.00196	25% Quartile		McChord AFB	0.00415	4.1496E-06	1.703	1.323

McGuire AFB

Single-Location			Dual-Location				
	Severity						
Probability	Mean	Median		Probability		Severity	
0.00203	1.451	1.037	West Coast Pair	Either	Both	Mean	Median
IQR			March ARB	0.00469	5.3998E-06	1.795	1.188
0.00284	75% Quartile		Travis AFB	0.00309	2.1518E-06	2.395	1.486
0.00184	25% Quartile		McChord AFB	0.00371	3.4104E-06	1.705	1.220

Westover ARB

Single-Location			Dual-Location				
	Severity						
Probability	Mean	Median		Probability		Severity	
0.00719	1.398	1.031	West Coast Pair	Either	Both	Mean	Median
IQR			March ARB	0.00985	1.91254E-05	1.769	1.185
0.01040	75% Quartile		Travis AFB	0.00825	7.6214E-06	2.369	1.483
0.00502	25% Quartile		McChord AFB	0.00887	1.20792E-05	1.678	1.217

Examining Tables 8 and 9, the study finds the probability range for a single-location to experience a disruptive adverse weather event as 0.00106 to 0.00719, where Travis AFB and Westover ARB represent the lower and upper bounds, respectively. The same probability range for a dual-location pair to experience a complete disruption is 2.152E-06 to 1.913E-05, where Travis AFB and McGuire AFB form the lower bound pairing. March ARB and Westover ARB pair together as the upper bound. The calculated probabilities demonstrate that a dual-location inventory posture is less likely to experience a complete disruption than the single-location option. The calculated severities provide a similar result, showing that a dual-location structure experiences less impactful disruptions when they do occur. For instance, the lower and upper bounds for the severity estimate of a single-location are Westover ARB and Travis AFB with values of 1.031 and 3.339, respectively. The severity estimate range for a dual-location pair is 1.185 to 2.809 with March AFB and Westover AFB creating the lower bound. Travis AFB and Charleston AFB create the upper bound pairing.

The results favor a dual-location structure over a single-location option in all cases. For instance, consider the United States experienced its current yearly average (*e.g.* 2599) of adverse weather events for the next twenty years, then coupling each location and structure probability estimate with the mean severity estimate, Travis AFB could conservatively expect to have 55.10 disruptions for a total duration of 183.97 days during the same period; whereas, the pair of Travis AFB and McGuire AFB would most likely experience 0.11 complete disruptions for a total duration of 0.27 days. The number of partial disruptions for the same pair is expected to be 160.62 with a duration of 384.68 days. In this case, the single-location encounters a complete disruption of operations 55 more times than the dual-location pair, a fairly significant disparity. Table 10 provides the same calculations for all locations and structures for comparison. It should be noted that partial disruptions are not considered when comparing single- versus dual-location structures due to the fact operations can still be conducted at one of the paired locations.

Table 10: Location and Structure 20 Year Expected Value Comparison

	# of Wx Events at All Locations	Total Days of Complete Disruption	# of Wx Events at Any Location	Total Days of Partial Disruption
McGuire + Travis	0.11	0.27	160.62	384.68
McGuire + McChord	0.18	0.30	192.85	328.71
Dover + Travis	0.14	0.33	183.49	439.09
Dover + McChord	0.22	0.37	215.72	367.26
Charleston + Travis	0.17	0.48	216.76	608.76
McGuire + March	0.28	0.50	243.79	437.60
Charleston + McChord	0.27	0.58	248.98	527.35
Dover + March	0.34	0.61	266.66	478.12
Westover + Travis	0.40	0.94	428.84	1015.70
Charleston + March	0.43	0.95	299.92	662.38
Westover + McChord	0.63	1.05	461.06	773.66
Westover + March	0.99	1.76	512.00	905.48
McGuire AFB	105.52	153.11	-	-
McChord AFB	87.33	170.99	-	-
Travis AFB	55.10	183.97	-	-
Dover AFB	128.39	185.78	-	-
March ARB	138.27	295.75	-	-
Charleston AFB	161.66	368.26	-	-
Westover ARB	373.74	522.48	-	-

Overall Risk

Provided the calculated probability and severity estimates, the two variables can now be presented in the final risk format. Table 11 presents the two overall risk values using both the mean and median severity estimates for each candidate location and structure. Table 11 also indicates the respective combined average rank of each location and structure in ascending order.

Reviewing the table, the optimal location and structure to reduce the overall risk profile of consolidating critical inventories is revealed as the dual-location pair of McGuire AFB and Travis AFB. The pair proves to be the top option when considering both complete and partial disruptions. Notice that regardless of using either the mean or median severity estimate, the same conclusion is reach when selecting a location of minimum overall risk.

Table 11: Location and Structure Overall Risk

	Overall Risk		Rank		
	Mean	Median	Mean	Median	Combined AVG
McGuire + Travis	5.1536E-06	3.1965E-06	1	1	1
Dover + Travis	6.2654E-06	4.1602E-06	3	2	2.5
McGuire + McChord	5.8147E-06	4.1606E-06	2	3	2.5
Dover + McChord	7.0668E-06	5.4917E-06	4	4	4
Charleston + Travis	9.2601E-06	5.5060E-06	5	5	5
McGuire + March	9.6926E-06	6.4127E-06	6	6	6
Charleston + McChord	1.1066E-05	7.3391E-06	7	7	7
Dover + March	1.1780E-05	8.4823E-06	8	8	8
Westover + Travis	1.8055E-05	1.1302E-05	9	9	9
Charleston + March	1.8274E-05	1.1352E-05	10	10	10
Westover + McChord	2.0269E-05	1.4705E-05	11	11	11
Westover + March	3.3833E-05	2.2664E-05	12	12	12
Travis	3.5390E-03	2.0505E-03	15	13	14
McGuire	2.9460E-03	2.1044E-03	13	14	13.5
McChord	3.2888E-03	2.3576E-03	14	15	14.5
Dover	3.5729E-03	3.0715E-03	16	16	16
March	5.6904E-03	3.5605E-03	17	17	17
Charleston	7.0853E-03	4.3727E-03	18	18	18
Westover	1.0049E-02	7.4162E-03	19	19	19

While the analysis provides a clear and objective course of action, it is important to consider the scope of this article. First, the study only accounts for equipment UTCs within the CONUS. The USAF CE community does maintain equipment UTCs overseas in both the Pacific

Air Forces (PACAF) and United States Air Forces in Europe (USAFE). If the analysis were to include these other geographical locations, the results may indicate a different acceptable structure. For instance, the risk threshold may prove substantially low enough to maintain only one CONUS inventory holding location, with other locations consolidated to PACAF and USAFE. Second, the study does not consider other decision criteria outside of risk. Namely, cost and manpower are not integrated within the analysis. Both criteria could shift the decision of positioning equipment UTCs at McGuire AFB and Travis AFB to an alternative location or structure. For example, the cost to maintain one, large facility may prove substantially lower than two, medium-sized facilities. As a result, the acceptable risk threshold of the USAF CE community may change when balancing other decision factors. Finally, through justification, the military case study was limited to only adverse weather events. That is not to say other internal or external risk agents cannot disrupt operations, but such agents played less of an impact in determining a geographical decision. Now that an optimal structure and corresponding locations have been identified, it would be beneficial to the USAF CE Community to assess the remaining risk agents to ensure effective countermeasures are in place. Even with the identified limitations, the analysis provides objective indication of how and where equipment UTCs should be postured to minimize overall risk exposure should a consolidation plan be pursued.

Conclusion

The military case study presented provides an objective approach to identifying risk agents, selecting a mitigation strategy, and quantifying risk associated with differing posture options for critical inventories. Pending the AFCEC's established risk threshold, the study recommends the CE community establish a dual-location inventory holding structure with equipment UTCs held at McGuire AFB and Travis AFB. Pursuing this strategy will establish an acceptable threshold for risk while allowing the CE community to take advantage of the many benefits offered through consolidation.

Further research should be conducted in the areas of initial implementation cost, facility life cycle cost, and manpower requirements associated with the different supply chain structures to provide comprehensive analysis pertaining to the CE community alternative options. Investigating such information allows senior leaders to examine all aspects of the problem at hand, ultimately leading to an informed, objective solution.

The military case study has implications for other functional areas within the DoD which maintain a dispersed posture and are considering consolidation of critical inventories. Other fields of interest are those who face a geographical decision of where to place various supply chain operations so that the probability and severity of disruption is minimized.

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IV. Scholarly Article: Manpower Implications of Consolidating United States Air Force Civil Engineer Contingency Equipment

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Abstract

The United States Air Force (USAF) Civil Engineer (CE) community is currently considering the consolidation of contingency equipment dispersed throughout the continental United States (CONUS). Certainly, several areas of research drive the decision on whether or not to centrally position wartime supplies such as cost, risk, and manpower. The research effort presented in this article investigates manpower implications that evolve from consolidation of CE war reserve materiel (WRM) and assignment of dedicated personnel to accomplish all tasks associated with said equipment. The study's findings indicate the CE community expends a significant amount of unaccounted manpower in the current equipment posture. Furthermore, by consolidating its WRM, the CE community stands to realize tremendous manpower efficiencies and savings. Such findings provide substantial direction for CE community decision-makers in objectively determining future critical inventory holding posture.

Key Words

Manpower; Consolidation; Civil Engineer; Contingency Equipment

Introduction

The United States Air Force (USAF) has always encouraged a culture of innovation amongst its Airmen. Through established programs such as Air Force Smart Operations for the 21st Century (AFSO21) and Air Force Innovative Development through Employee Awareness (IDEA), the Air Force continually seeks to improve its way of doing business. Often, these programs result in better business practices that produce significant process efficiencies and increasingly support effective execution of critical operational concepts. Recently, the Department of Defense (DoD), to include the USAF, placed renewed emphasis on investigating and implementing such practices due to the substantial funding cuts levied by the Budget Control Act (BCA) of 2011 (BCA, 2011). In fact, through various efficiency initiatives, the uniformed services estimated savings during Fiscal Year (FY) 2012 and FY 2013 to approach upwards of $33 billion (DoD, 2011, DoD 2012). While these savings are significant, efforts must persist to continually find additional efficiency and savings throughout the DoD and USAF due to mandated budget reductions through 2022 (BCA, 2011).

One practice that holds both operational efficiency and savings potential for the USAF is the consolidation and forward positioning of war reserve materiel (WRM). Recently performed posturing studies within the Security Forces and Medical fields indicate that consolidation of dispersed WRM leads to efficiencies in inventory management, readiness, transportation, and manpower (Overstreet, 2004; Skipper, Bell, Cunningham, and Mattioda, 2010). Within the Security Forces study, for example, the average transportation savings realized through consolidation when shipping a standard deployment tasking was in excess of $90,000 (Skipper *et al.*, 2010). Similarly, the Medical study cites overall savings of $298,000 annually (Overstreet, 2004). Certainly the studies offer viable solutions with desired cost savings in a time of looming financial hardship; however, Air Force functional areas must carefully examine several important aspects prior to pursuing such a critical strategic decision. For instance, what initial transportation cost is required to implement consolidation? What risk profile do the various supply structure options present? Or, what level of manpower is necessary to support such an alternative posture? While there are undoubtedly further questions requiring answers, this article focuses on issues concerning manpower. The military case study presented hereafter offers both insight and instruction regarding manpower implications that evolve from the consolidation of WRM.

Background & Problem Statement

The USAF Civil Engineer (CE) community maintains contingency equipment required for the execution of military operations in austere environments. The equipment includes resources needed for the construction, maintenance, and repair of infrastructure vital to the support and sustainability of deployed personnel. To effectively transfer the assets into overseas theater locations, the CE community, to include other functional areas, bundles equipment into Unit Type Codes (UTCs) to create modular, scalable packages that can be tailored to meet mission sets of variable scope. Currently, the UTCs are dispersed throughout the continental United States (CONUS) at various USAF installations.

In October of 2012, the Air Force Civil Engineer Center (AFCEC) released a study concerning the current posture of equipment UTCs maintained by the CE community. The results cite inconsistencies in handling, tracking, and capability reporting due to the geographical separation of equipment; in addition, the study documents system redundancies that create unneeded waste (AFCEC, 2012). Furthermore, the dispersed posture requires several points of contact to transfer UTCs within the CONUS prior to overseas shipment; the excess handling, coordination, and movement creates a slow, burdensome deployment process that drives up cost and enables delay (Overstreet, 2004). As a result of the current system inadequacies, the CE community began to review alternative options for equipment UTC positioning within the CONUS. The investigation included several military studies suggesting the consolidation and forward placement of inventories results in cost savings and substantial efficiencies over a dispersed posture (Overstreet, 2004; Skipper *et al.*, 2010). Due to these findings, the AFCEC proposed three courses of action (COAs) for further analysis:

1. Maintain current dispersed posture
2. Establish one CONUS holding location near a Port of Embarkation (POE)
3. Establish two CONUS holding locations, one on the west and east coast near a POE

Given the problem's inherent complexity, the CE community enlisted the help of the Air Force Institute of Technology (AFIT) to analyze the alternative options for equipment UTC posture within the CONUS while considering resultant manpower implications. Specifically, the analysis investigates three distinct research objectives listed hereafter:

1. Report the current level of manpower expended to support inventory operations for the geographically dispersed equipment posture
2. Report aspects of both consolidation and assignment of dedicated personnel that hold potential for manpower efficiency
3. Report the expected manpower efficiency should consolidation and assignment of dedicated personnel be pursued

The three research objectives translate into key decision criteria that will indicate the expected level of manpower required to support an alternative posture for critical inventories and identify any subsequent savings. Lastly, this study only considers equipment UTCs identified in Table 1 under the control of active duty personnel, due to data collection limitations.

Table 1. Active Duty CONUS Postured Equipment UTCs

UTC	# CONUS Postured by Active Duty	Description
4F9EE	10	Pest Management Support Equipment
4F9EF	25	Sustainment Follow-on Equipment Set
4F9EH	11	Survey Support Equipment Set
4F9ET	21	Engineer Sustainment Equipment Set
4F9FE	6	Firefighter Communications Package
4F9FF	8	Firefighter SCBA Compressor
4F9FJ	20	Firefighter Management 2 PK Team
4F9FX	3	Firefighter Limited Equipment Set
4F9WL	10	Active CBRN Response
4F9WN	14	CBRN Detection
4F9WP	15	CBRN Detection Augmentation
4F9WS	9	CBRN Personnel Decontamination
4F9X1	54	EOD Core Equipment
4F9X3	40	EOD Base Support Sustain Equipment
4F9X6	27	EOD Vehicle Support Package
4F9X7	13	EOD Large Robotics Platform
TOTAL	286	

(DAF, 2011a; AFCEC, 2013a)

Literature Review

This literature review focused on both the current and potential future posture of CE equipment UTCs. Each ensuing section presents the latest developments in subject areas relevant to the military case study. The initial subject area examines CE equipment UTCs and their importance in supporting critical operational concepts and objectives; successive sections examine the current state of equipment UTC posture and manpower, the potential future state of equipment UTC posture and manpower, and the research techniques/methods utilized to facilitate this study's findings.

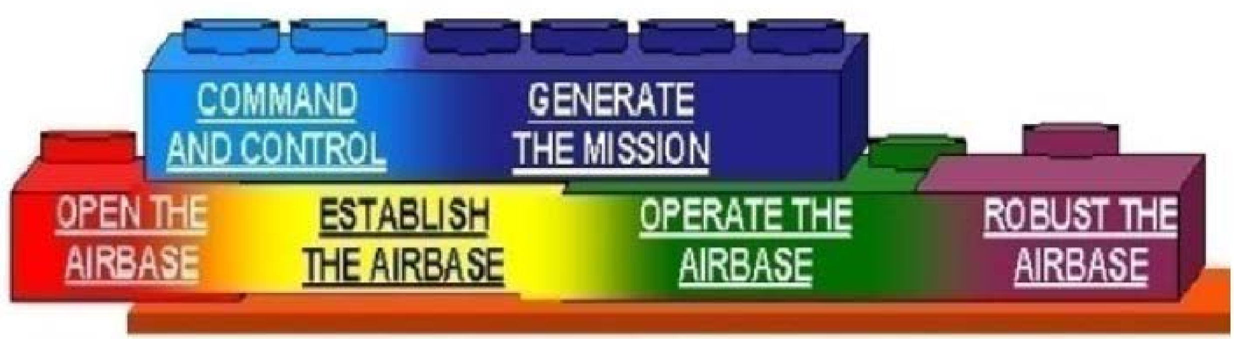
CE Equipment UTCs

UTCs are developed by bundling equipment sets to create modular, scalable packages that present a specific function or capability. The modular and scalable nature of UTCs enables deployed commanders to source said functions or capabilities in the necessary amount to effectively complete mission goals. Essentially, UTCs act as building blocks, facilitating the ability to employ tailored equipment sets to support the downrange requirements of USAF personnel (DAF, 2006a; DAF 2006b; DAF, 2011b; DAF, 2012a; DAF, 2013a). To provide an example, an equipment UTC might consist of surveying tools that allow USAF personnel to successfully complete base layout and construction activities. Should a commander require such tools, the specific equipment UTC can be sourced and deployed to the necessary location. Depending on the magnitude of work, multiple sets of the equipment UTC can be requested. The ability to source precise equipment in needed capacities directly coincides with the operational concept of focused logistics. The Chairman of the Joint Chiefs of Staff (CJCS) defined focused logistics as “the ability to provide the joint force the right personnel, equipment, and supplies in the right place, at the right time, and in the right quantity, across the full range of military operations” (CJCS, 2000). Markedly, the modular, scalable configuration of equipment UTCs plays an important role in supporting the implementation of such a concept.

Beyond configuration, the composition of CE equipment UTCs proves just as critical. CE equipment UTCs are made up of resources needed for the construction, maintenance, and repair of infrastructure vital to the support and sustainability of deployed personnel. More explicitly, CE equipment UTCs enable six force modules (Figure 1) essential to the establishment of forward operated airbases identified as: open the airbase, command and control, establish the airbase, generate the mission, operate the airbase, and robust the airbase. Referring to

Department of the Air Force (DAF) publications, force modules are defined as “the framework to systematically present capability to rapidly open an airfield, establish operational capability and conduct air operations thereafter” (DAF, 2006a; DAF, 2006b; DAF, 2012a). Figure 1 provides an illustration of the six force modules and their order of execution to effectively establish a forward operated airbase.

Figure 1. Force Modules Supported by CE Equipment UTCs



(DAF 2006a; DAF, 2006b; DAF, 2012a)

CE equipment UTCs are sourced and deployed throughout force module execution to erect and sustain infrastructure required to successfully conduct combat or humanitarian operational objectives (DAF, 2012b). Referencing the prior surveying example, an equipment UTC comprised of such tools is needed to effectively site operating locations for different entities, to maximize efficient space utilization, and mitigate potential airfield obstructions. Without the resource composition of CE equipment UTCs, the ability for the USAF to project power by establishing forward warfighting platforms would be substantially diminished.

CE equipment UTCs evidently play a critical role in supporting operational concepts and objectives through their configuration and composition. As a result, due diligence must be performed when making strategic decisions that could affect CE equipment UTCs and their employment in contingency activities. This certainly extends to the investigation of alternative equipment posturing and the level of manpower required to successfully sustain such a transition.

Current State

Posture

The current equipment UTC posture is driven by forecasted wartime requirements and the ability to rapidly employ and execute force modules needed for the establishment of a set number of forward operating airbases (DAF, 2006b). Based on these requirements, Headquarters (HQ) USAF provides guidance indicating the number and type of equipment UTCs to be postured by each Major Command (MAJCOM) depending on their respective missions and needed capabilities. In turn, the MAJCOMs then distribute these equipment allocations amongst units within their command utilizing similar criteria (DAF, 2006b; DAF, 2012c). Units are then required to posture the assigned equipment UTCs and ultimately become accountable for the managing, reporting, handling, and maintaining duties (DAF, 2012c). Referencing AFCEC documents issued in January of 2013, the aforementioned process has resulted in the posturing of 832 CONUS-based CE equipment UTCs maintained by 163 USAF active duty, reserve, and Air National Guard (ANG) units; the current layout positions the equipment UTCs at 116 geographically separated locations (AFCEC, 2013b). While the dispersed posture results in significant redundancy and mitigates the potential for a single point of failure, it also produces substantial inconsistencies in executing associated duties across units and causes excessive coordination to facilitate equipment changes, movement, and reporting (Overstreet, 2004; AFCEC, 2012). Such issues might be resolved through an alternative posture.

Manpower

The USAF currently quantifies the number of personnel required to successfully execute civil engineer peacetime operations through established processes as outlined within DAF publications (DAF, 2013b; DAF 2013c). Initially, manpower planning and programming occurs at HQ USAF where requirements are derived from the national security policy. Derived requirements transfer through the chain of command to provide personnel allocations for respective commands to complete assigned missions (DAF, 2013b; DAF, 2013c). To facilitate commanders with identifying the “minimum and essential manpower required to accomplish approved missions”, the Air Force Management Engineering Program (MEP) provides a framework to develop manpower standards (DAF, 2013b).

Manpower standards result from rigorous procedures requiring specific analysis methods that meet set statistical requirements (DAF, 2003; DAF, 2007; DAF, 2013b). Such standards typically provide an equation that utilizes one or more variables to arrive at the total manpower required to complete a compiled list of tasks. In addition, the standards often detail the number of man-hours required to complete a particular task and the average number of times that task will be accomplished within a specified period (DAF, 1997a; DAF 1997b; DAF 1997c; DAF 1997d; DAF, 2000a; DAF, 2000b). Due to the variance in tasks across different functional areas within the USAF, manpower standards are generally created at the flight level. Accordingly, the CE community utilizes fifteen different manpower standards to determine the overall end strength required for each unit (DAF, 2003). Table 2 provides both the functional account code (FAC) and title for each manpower standard applicable to civil engineers.

Table 2. USAF CE Manpower Standards

FAC	Title	FAC	Title
44CE	Base Civil Engineer	44EO	Operations
44EB	Readiness	44EP	Acquisition & Liaison CE
44EC	Engineering	44EQ	Contracted CE Support
44ED	Explosive Ordinance Disposal	44ER	Resources
44EF	Fire Protection	44ES	Site/Radar CE Support
44EH	Housing	44ET	Site/Range CE Support
44EI	Sci Facil CE Supt	44EV	Environmental
44EN	Nonstd Unit CE Support		

(DAF, 2003)

In reviewing applicable CE manpower standards, the AFCEC determined, with exception to the Readiness Flight, that none captured tasks associated with the managing, reporting, handling, and maintaining of equipment UTCs; therefore, all manpower contributed by other CE flights in accomplishing said tasks is taken “out of hide” and detracts from the total man-hours allocated toward executing primary functions (AFCEC, 2012). In addition, such work is assigned as an “additional” or secondary duty, causing tasks to be completed by any available personnel which results in significant variation with respect to how the managing, reporting, handling, and maintaining of equipment UTCs is accomplished (AFCEC, personal communication, January, 2014). Ultimately, the CE community is expending manpower on unaccounted duties and, as a result, is requiring more work of its personnel than what they are able to accomplish. Due to the importance of CE equipment UTCs, these tasks must be accomplished regardless of the lack of manpower.

Appropriately, the first objective of this article attempts to capture the current level of manpower expended to support inventory operations for the geographically dispersed equipment posture. Recording the current man-hours required to complete tasks associated with the managing, reporting, handling, and maintaining of CE equipment UTCs is a critical first step in forecasting requirements for an alternative posture. Details concerning the process for establishing a manpower baseline for the current state are discussed further in the Methodology.

Future State

Consolidation

The potential future posture for CE equipment UTCs includes the consolidation of inventories to one or two locations. This realignment of equipment position is expected to gain substantial efficiencies and savings over the current state (AFCEC, 2012). Such an expectation is well-founded throughout inventory consolidation literature. For instance, a large contingent of researchers investigated and determined consolidation facilitates reductions in inventory due to the effects of pooling (Maister, 1976; Eppen, 1979; Zinn, Levy, and Bowersox, 1989; Ronen, 1990; Mahmoud, 1992; Tallon, 1993; Evers and Beier, 1993; Tyagi and Das, 1998). Inventory pooling is defined by the ability to aggregate demand across multiple locations and service customers from fewer facilities than previously in place (Swinney, 2012). Accordingly, an organization will realize less demand variability and effectively reduce overall operational costs (Wanke and Saliby, 2009; Swinney, 2012). Such findings are complemented by military studies that cite consolidation of WRM leads to increased inventory readiness, asset visibility, and quality control (Overstreet, 2004; Skipper *et al.*, 2010). Patton (1986) provides a comprehensive list of benefits detailed in Table 3.

Table 3. Benefits of Consolidation

Reduced factory to distribution transport costs	Better warehouse management	Consistent stock availability
No cross-hauling between locations	Reduced stock holdings	Economies of scale
Better transportation negotiation	Improved automation	Improved stock turnover

(Patton, 1986)

The aforementioned benefits certainly support the CE community's proposal to pursue a central structure of inventory holding over the current state. However, Patton (1986) highlights potential drawbacks of consolidation to include longer order cycle times and increased transportation costs. Fortunately, by coupling consolidation with forward positioning such issues can be mitigated.

Forward Positioning

The potential future posture for CE equipment UTCs includes the forward positioning of inventories near POEs. Forward positioning generally refers to the advanced placement of inventory in close proximity to the end-user. As alluded to in the previous section, the act of positioning inventories forward in the supply chain leads to shorter order cycle times and decreased transportation costs (Skipper *et al.*, 2010). Extant literature on forward positioning and related concepts thoroughly substantiates such claims. For example, Ho and Perl (1995) examined service-sensitive demand with respect to warehouse location, finding that higher responsiveness to sensitivity is achieved by placing goods closer to the customer. Such a capability proves critical in military operations where high degrees of responsiveness are required to effectively combat enemy actions. Several other studies also indicate forward positioning as a viable solution for such demand, often citing reduced closure time and transportation costs as typical results (McNulty, 2003; Amouzegar, Tripp, and Galway, 2004; Ghanmi and Shaw, 2008; McCormick, 2009). For example, Ghanmi and Shaw (2008) indicate the use of forward positioning led to a twelve day reduction in closure time on objectives for Canadian Forces and reduced airlift related costs by 17%. As is often the case, such findings prove to be variable based on the particular scenario analyzed. For instance, Skipper *et al.* (2010) cites a reduction in closure time close to four days and transportation savings upwards of

$90,000 each time a standard Security Forces equipment UTC tasking is deployed. Much like the CE equipment UTC proposal, savings were achieved simply by transitioning Security Forces equipment UTCs from a dispersed posture within CONUS to a consolidated holding structure near a POE.

As confirmed by the literature, when coupled together, both consolidation and forward positioning realize substantial benefits that maintain the potential to remedy issues resulting from the current state of CE equipment UTCs. While these benefits certainly validate the CE community's proposal to pursue an alternative posture, questions concerning resultant manpower implications still remain unanswered.

Manpower

Many researchers have investigated inventory consolidation and determined resultant efficiencies and savings; however, few have examined the implications on manpower. In fact, during the course of this study only two published articles were identified that directly linked consolidation with subsequent manpower efficiency (Skipper *et al.*, 2010; Handy, Mallette, Crosslin, James, and Sherbrooke, 1991). While this offers less insight as to the scale of manpower efficiency to be gained through consolidation of CE equipment UTCs, it does not detract from the fact that such efficiency can be realized. For instance, Skipper *et al.* (2010) indicates all tasks associated with Security Forces equipment UTCs could be accomplished with 402 man-hours at a consolidated location as opposed to the 1248 man-hours required in a dispersed posture. The findings yield a manpower efficiency of over 67%. Handy *et al.* (1991) suggests the consolidation of five San Francisco Bay Area supply depots realized a manpower efficiency of close to 13%. Certainly, several factors drive the scale of manpower efficiency to be gained through consolidation; accordingly, the level of efficiency generated by consolidating CE equipment UTCs is likely different from both of the aforementioned studies.

The inability to simply transfer previously determined figures from earlier findings drives the impetus for the latter two objectives of this study. Objective Two identifies aspects of both consolidation and assignment of dedicated personnel that hold potential for manpower efficiency. This study addresses the assignment of dedicated personnel due to tasks in the current state being completed as an “additional duty”. By identifying such aspects, it provides managers and supervisors direction on which items require added interest or focus to ensure the expected manpower efficiency materializes. Objective Three attempts to forecast the expected manpower efficiency gained through proper implementation of the aspects derived from Objective Two.

Forecasting manpower, to include efficiency, can be accomplished in a number of ways: historical data comparison, regression modeling, sensitivity analysis, or simulation (Milkovich, Annoni, and Mahoney, 1972; Wong, Chan, and Chaing, 2012). However, in the absence of reliable empirical data, eliciting expert opinion through various methods, namely the Delphi technique, proves to be a viable forecasting approach (Milkovich *et al.*, 1972; Rowe and Wright, 1999; Linstone and Turoff, 2002). Given the current data limitations, this study uses the elicitation of experts in completing both Objectives Two and Three.

Eliciting Expert Opinion

There are several techniques available to the research community that facilitate soliciting experts and subsequently analyzing their inputs. Among the most widely used methods are surveys, interviews, focus groups, and questionnaires, all of which have their advantages and disadvantages depending on the circumstances surrounding their application (Hager, 2013).

Surveys generally consist of numerous questions that are posed to a large, randomly selected sample of participants (Neumann, 2006). Responses are analyzed using descriptive statistics to make judgments concerning the characteristics or opinions of the targeted population (Neumann, 2006; Hager, 2013). The scopes of surveys are restricted to the timeframe in which they are conducted and little opportunity exists for follow-up or clarifying questions (Leedy and Ormrod, 2001; Hager, 2013). Perhaps of particular importance, surveys tend to capture and describe the present versus projecting or forecasting the future (Miller, 2006; Hsu and Sanford, 2007). Given the objectives of this study are concerned with the future state of CE equipment UTC posture, the use of a simple survey was deemed inappropriate.

Another method for eliciting expert opinion is the employment of interviews, either open-ended or semi-structured. Such interviews are typically conducted face-to-face or via telephone and often yield a substantial amount of information about the topic under investigation (Leedy and Ormrod, 2001; Hager, 2013). Unfortunately, execution of this method requires significant time commitment on behalf of the participant and researcher. In addition, comparisons across interviewees may prove infeasible without subsequent sessions for follow-up or clarification (Leedy and Ormrod, 2001; Neumann, 2006). Provided the time constraints imposed on this study and the excessive coordination required in implementing an interview method, it was not selected for use in the course of this research.

Utilizing focus groups proves a viable alternative to interviewing methods, producing similar results in a compressed timeframe (Leedy and Ormrod, 2001). Rather than one-on-one interaction, this method facilitates discussion concerning the topic of interest in a group setting with all selected participants (Leedy and Ormrod, 2001; Neumann, 2006). Employing focus groups often allows for the synthesis of ideas across participants and reveals issues that otherwise would have been uncovered (Rowe and Wright, 1999; Neumann, 2006). However, the method requires geographical co-location of participants and introduces several biases into the research study. For instance, the participation of some members may be limited or stifled due to the prominence of a socially dominant individual within the group (Rowe and Wright, 1999). If not for the geographical requirements of implementing a focus group, the method meets the requirements for this study. The Delphi technique proves a practical alternative that captures the benefits of the focus group, but also eliminates the obstacles of geographical separation and other biases (Dalkey and Helmer, 1963; Rowe and Wright, 1999).

Using focused questionnaires over a series of rounds, the Delphi method directs expert opinion toward a particular topic so that a constructive group discussion and subsequent solution can be realized (Dalkey and Helmer, 1963; Linstone and Turoff, 2002). By employing questionnaires, participants retain their anonymity and are not required to be in the same location simultaneously for the study to take place (Rowe and Wright, 1999). Skulmoski, Hartman, and Krahn (2007) indicate the method "works well when the goal is to improve our understanding of problems, opportunities, solutions, or to develop forecasts." Furthermore, the method allows for follow-up or clarification of responses to ensure the researcher accurately captures an individual's perspective concerning the issue at hand. Given these benefits and the circumstances surrounding this study (*e.g.* geographically dispersed experts), the study elected to use the Delphi method in achieving its objectives.

Methodology

Establishing the Manpower Baseline

Data Collection

Without established manpower standards capturing the level of effort CE personnel contribute to managing, reporting, handling, and maintaining equipment UTCs, deriving a reasonable estimate required the collection of data from the CE community. To facilitate such collection, the AFCEC initiated a data call requesting units to estimate the number of man-hours expended for a given fiscal quarter accomplishing all duties associated with CE equipment UTCs under their control. Appendix A presents an example of the data collection tool utilized to acquire unit inputs. Leveraging the chain of command, the data call was distributed to nearly 190 different CE units (AFCEC, personal communication, October, 2013). After dissemination, units were allotted approximately three weeks to provide their inputs prior to data call closure. The AFCEC then transferred all data over to the AFIT for analysis within this study.

Data Review

Upon receipt from the AFCEC, the data was aggregated by unit. In accomplishing data quality control, the data revealed instances where different sections of the same unit reported on equipment UTCs particular to their trade or specialty. In such cases, the study compiled the inputs for each section under the unit to which they were assigned. In addition to the aforementioned issue, duplicate entries were also identified and subsequently removed from the data set, resulting in 34 total data points. The quarterly inputs were then reduced to monthly estimates (dividing by three) to simplify further comparison and review. Following estimate reduction, the data points were scrutinized for “bad” or unreliable inputs. For example, one data point revealed an estimate surpassing the available number of man-hours in a month for the team size specified. Others data points revealed units inputting the same number of man-hours for each of the 16 different equipment UTC types, even though the composition and complexity of tasks varied significantly from one equipment UTC type to the next. Accordingly, such inputs were removed due to their unreliability, resulting in a total of 31 data points used in this study, a response rate of 16.3%.

The final structure of the data represented each unit by a separate data point. In turn, each data point also detailed its respective unit's inputs for the different equipment UTC types under its control. For example, a data point might represent Unit 3. If this unit were assigned all 16 different equipment UTC types, it would have provided man-hour inputs for each one. To further clarify, perhaps another data point identified as Unit 4 only has equipment UTC types designated as 4F9EE and 4F9X7, then Unit 4 would only provide man-hour inputs for those two different types. Figure 2 provides an illustration of this example as well as a simplified version of the final data set structure.

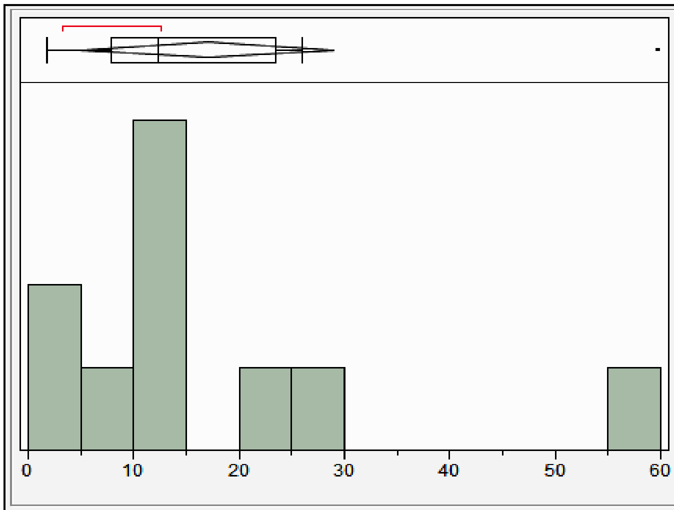
Figure 2. Final Data Set Structure

	4F9EE				4F9EF				...				4F9X7			
Unit	Monthly Man-Hours/UTC	# UTCs	Task 1	Task n	Monthly Man-Hours/UTC	# UTCs	Task 1	Task n	Monthly Man-Hours/UTC	# UTCs	Task 1	Task n	Monthly Man-Hours/UTC	# UTCs	Task 1	Task n
1																
2																
3	6	4	10	14	4	1	3	1	...	...	...	...	4	3	8	4
4	5	2	2	8									6	1	3	3
5																
k																

<u>Data Analysis</u>

Having reviewed and distilled all inputs into the final data set structure, analysis began by developing distributions for all 16 equipment UTC types using the total monthly man-hours per UTC field. Figure 3 depicts an example of the distributions formed to include related descriptive statistics.

Figure 3. 4F9ED Total Monthly Man-Hours per UTC Distribution



Quantiles

100.0%	maximum	59.6667
99.5%		59.6667
97.5%		59.6667
90.0%		56.3
75.0%	quartile	23.5
50.0%	median	12.2917
25.0%	quartile	7.8125
10.0%		1.9
2.5%		1.75
0.5%		1.75
0.0%	minimum	1.75

Moments

Mean	17.025
Std Dev	16.738228
Std Err Mean	5.2930925
Upper 95% Mean	28.998807
Lower 95% Mean	5.0511928
N	10

Examining the distributions for each respective equipment UTC type revealed a high degree of variation in the number of man-hours required to complete associated tasks. For instance, the monthly range reported for the 4F9ED equipment UTC was from 1.75-59.67 hours, with the mean and standard deviation holding close to the same value. Several attempts were made to explain such variability by using other available data fields. For example, could the differences be attributed to geographical location, the commanding MAJCOM, or the team size available to complete tasks? Unfortunately, attempts to explain the variation were unsuccessful. Consequently, this produced a certain degree of uncertainty and simply using a measure of central tendency to develop a reliable manpower estimate was deemed infeasible. As a result, this study elected to employ a Monte Carlo simulation in the former method's place.

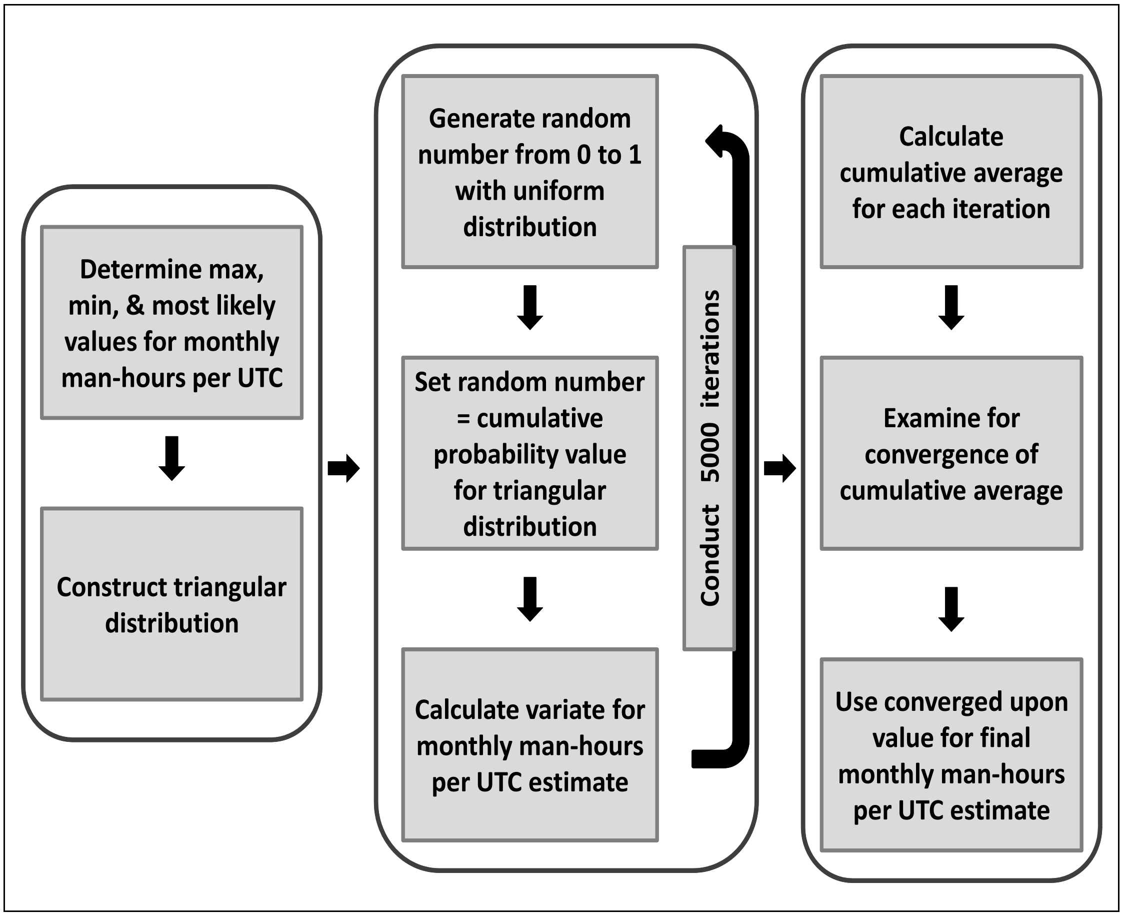
Simulation

To carry out the proposed simulation, it is necessary to identify a distribution that adequately models all 16 equipment UTC types. Referencing the distributions previously developed, the data proved too sparse to easily recognize an apparent form. Accordingly, the study assumed each distribution to be triangular. A triangular form was selected because of its ability to adequately model skewed distributions; in addition, both upper and lower limits are defined mitigating the potential for extreme values (Petty and Dye, 2013). When defining a triangular distribution for simulation, three points are required which are typically garnered from either "experts" or historical data: the maximum, the minimum, and most likely values (Bodily, 1983; Petty and Dye, 2013).

The mode is often utilized as the "most likely value". But, due to the continuous and variable nature of the inputs collected in this study, no distribution presented a value that repeatedly occurred with any consistency. For that reason, the study employed both the mean and median instead. To make clear, two separate simulations were run for each equipment UTC type. One simulation used a triangular distribution with the most likely value represented by the mean. The other simulation used a triangular distribution with the most likely value represented by the median. As for the maximum and minimum values, those were set to correspond with maximum and minimum values from each equipment UTC distribution previously developed.

Having determined an adequate distribution form and the values needed for its construction, the steps outlined in Figure 4 were followed to implement a simulation for each of the 16 equipment UTC types. The result of each simulation produced an overall estimate of monthly man-hours per UTC, for each equipment UTC type.

Figure 4. Simulation Process



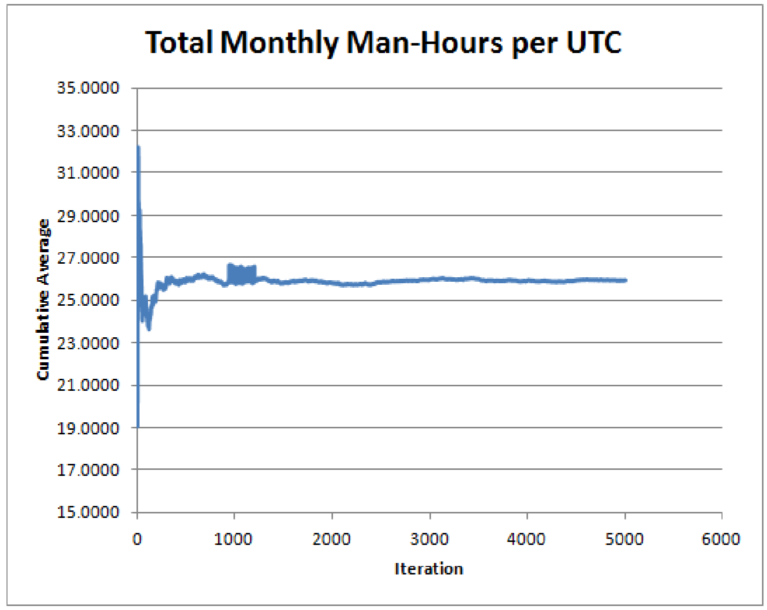
To help illuminate the simulation process, Figure 5 demonstrates the actual spreadsheet set-up to include the first 10 iterations for the 4F9ED simulation using the mean value for construction of the triangular distribution. In addition, Figure 5 also shows the resulting 4F9ED cumulative average and convergence to the final estimate.

Figure 5. Simulation Spreadsheet Set-up and Cumulative Average Chart

Triangular Distribution	
Min	1.7500
Max	59.6667
Mean	17.0250
Range	57.9167
LSR	15.2750
RSR	42.6417

4F9ED

Iteration	RN	Variate	CUM Avg
1	0.1919	14.7779	19.0352
2	0.1348	12.6706	27.2205
3	0.3420	19.1453	26.3561
4	0.9158	45.2485	24.7701
5	0.6268	29.3062	29.9866
6	0.4632	23.2550	29.8025
7	0.5207	25.2626	32.1635
8	0.7713	35.9021	31.7744
9	0.3965	21.0620	31.0406
10	0.5739	27.2278	29.6365

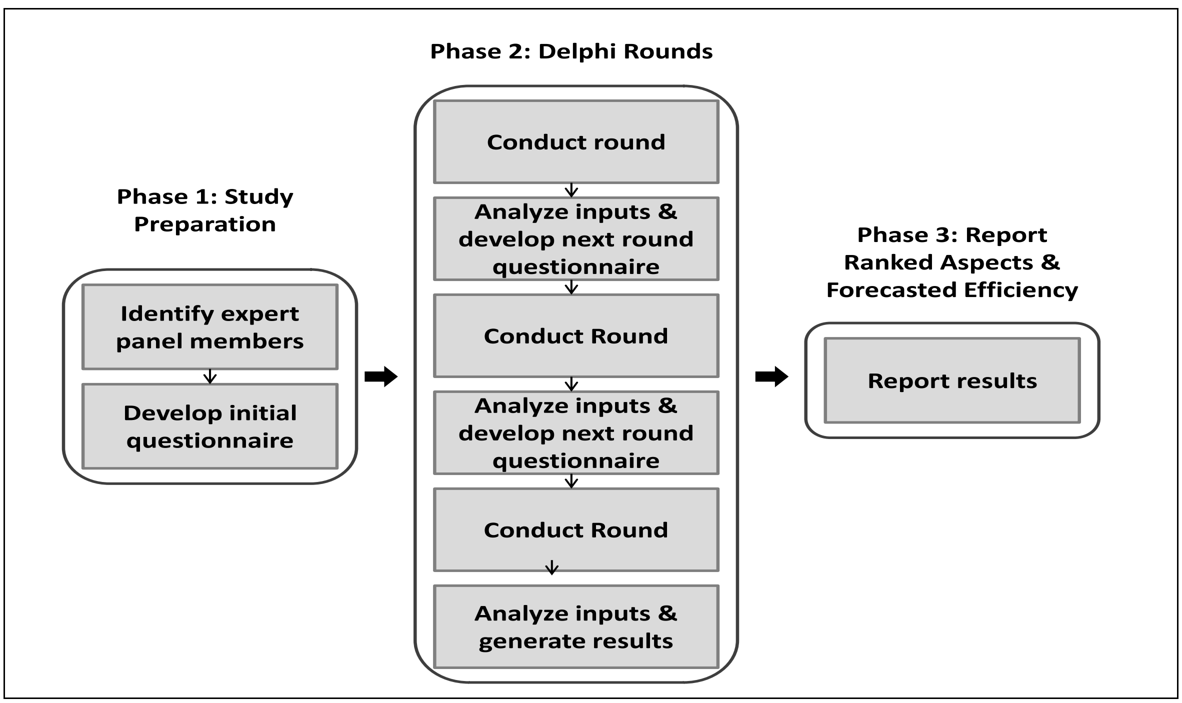


Using the total monthly man-hours per UTC estimate for each equipment UTC type from the simulation, the estimates were multiplied by the corresponding quantity of that equipment UTC type currently postured by the USAF. The result generated a monthly estimate for the total number of man-hours contributed to the managing, handling, reporting, and maintaining of all CE equipment UTCs. Subsequently, the monthly total was multiplied by 12 to represent an annualized figure. Note that this analysis resulted in two overall estimates, one utilizing a triangular distribution with a mean value and the other using a triangular distribution with a median value. Overall results are discussed further in the Results section.

Identifying Aspects and Forecasting Efficiency

Throughout the literature there exist several variations of the Delphi technique; in most cases, researchers select and employ the variant which best suits their stated objectives (Hasson and Keeney, 2011). Considering the latter two objectives of this article and available means, this study elected to synthesize both the “ranking-type” and “forecasting” Delphi methods. For clarification, the second objective—report aspects of both consolidation and assignment of dedicated personnel that hold potential for manpower efficiency—closely aligns with the ranking-type method employed by Martin (2009). The third objective—report the expected manpower efficiency should consolidation and assignment of dedicated personnel be pursued—best aligns with the forecasting method utilized by Milkovich *et al.* (1972). Tthe process to execute both Delphi variants is similar with slight differences attributed to determining consensus or stability of expert responses. Accordingly, the study adapted and applied a phased process approach exhibited by Huscroft (2008) and modified by Martin (2009). Figure 6 provides a graphical depiction of the applied process.

Figure 6. Delphi Method Phased Process Approach



(Huscroft, 2008; Martin, 2009)

Phase 1: Study Preparation

Phase One requires the identification and selection of expert participants who maintain the requisite knowledge needed to resolve the Delphi study objectives. Okoli and Pawlowski (2004) cite this step as being particularly critical due to the Delphi method relying on the opinion of a small group of experts rather than the collective inputs of a larger statistical sample. Accordingly, the Delphi literature provides several criteria to facilitate selecting expert panel members (Skulmoski *et al.*, 2007; Hager, 2013). Ultimately, this study chose to employ the criteria proposed by Adler and Ziglio (1996), where an expert exhibits: 1) Knowledge and experience with the matter being investigated, 2) Capacity and motivation to participate, 3) Adequate time to participate, and 4) Ability to effectively communicate. To facilitate the selection of experts, the AFCEC identified individuals within the CE community that met the required criteria, with increased emphasis placed on individuals possessing significant experience with managing, reporting, handling, and maintaining equipment UTCs.

The next step of Phase One concentrated on the initial questionnaire. Relying on precedent set by other researchers, the study began with open-ended questions to illuminate applicable issues and guide subsequent rounds (Schmidt, 1997; Hsu and Sanford, 2007; Martin, 2009). In addition to the open-ended questions, other demographic data was requested from the experts to help validate their expertise with regards to the subject being investigated. Table 4 depicts all questions included within the initial questionnaire, with the complete questionnaire located in Appendix B. With experts selected and the initial questionnaire ready for distribution, the study progressed to Phase Two in which the actual Delphi rounds were conducted.

Table 4. Initial Questionnaire Questions

Background Questions	
1	How many years of experience do you have in the USAF CE functional community?
2	How many years of experience do you have that directly or indirectly contribute to managing, reporting, handling, and maintaining CE equipment UTCs at either the tactical or operations level?
3	What is your current duty position?
Research Questions	
1	What aspects, if any, of consolidating CE equipment UTCs to one or two locations do you perceive would contribute to manpower efficiency in managing, reporting, handling and maintaining said UTCs over the current system in place?
2	What aspects, if any, of assigning dedicated personnel whose primary and only responsibility is managing, reporting, handling, and maintaining CE equipment UTCs do you perceive would contribute to manpower efficiency in said duties over the current system in place?
3	Considering all aspects you identified in Questions 1 and 2, what percent manpower efficiency change (improvement or decline) would you expect in the consolidation of equipment UTCs to one or two locations with the assignment of dedication personnel?

Phase 2: Delphi Rounds

Phase Two included three Delphi rounds; each round conducted sought to progress the stated research objectives. Prior to the start of Round One, the study elected to use electronic mail (e-mail) as the communication medium due to its ability to significantly reduce turnaround time between sending questionnaires and receiving responses (Sheehan and McMillan, 1999). Furthermore, web-based applications, such as e-mail, have been shown to produce improved response rates with comparable data quality to traditional mailing methods (Griffis, Goldsby, and Cooper, 2003).

The initial questionnaire distributed in Round One solicited experts to illuminate aspects of the future CE equipment UTC posture that would contribute to manpower efficiency over the current state. In addition, experts formulated their best estimate of the manpower efficiency to be gained (or lost) contingent on all of the aspects they identified being successfully implemented. Once responses were collected, all aspects were compiled based upon their content and the component they fell under; the components being either consolidation or assignment of dedicated personnel. The forecasted efficiency was also recorded and associated descriptive statistics generated. To ensure the compiled list of aspects accurately reflected the inputs of the experts, it was returned to the panel for confirmation. Schmidt (1997) indicates such confirmation is needed to validate the compiled list of aspects and substantiate conclusions resulting from the Delphi study conducted. The compiled list of aspects and associated descriptions disseminated to the expert panel is located in Appendix C.

Having successfully compiled and validated all aspects identified in Round One, the Round Two questionnaire focused on ranking each aspect based on its relative criticality to achieving the forecasted manpower efficiency. Explicitly, experts ranked the items under each component based on what they perceived was most critical for management to focus on successfully implementing so that the expected manpower efficiency would be realized. In addition, experts were given the opportunity to revise their initial efficiency estimate based on the compiled list and the median value of the forecasted manpower efficiency from Round One. The complete questionnaire issued for this round is located in Appendix D. After responses were collected, the study developed a weighted list of aspects for each component; the weighted list was based on the average rank generated across inputs (Martin, 2009). In addition, Kendall's Coefficient of Concordance (*W*) was used to indicate the level of consensus between experts (Schmidt, 1997; Martin, 2009). Table 5 provides the interpretation of Kendall's *W*. Lastly, stability of the manpower efficiency estimate was analyzed by comparing both the current and previous round's median and interquartile range (IQR) values. The study sought for the median value to remain constant and the IQR to converge or tighten (Milkovich *et al.*, 1972).

Table 5. Kendall's Coefficient of Concordance (*W*) Interpretation

W	Interpretation	Confidence in Ranks
.1	Very weak agreement	None
.3	Weak agreement	Low
.5	Moderate agreement	Fair
.7	Strong agreement	High
.9	Unusually strong agreement	Very high

(Schmidt, 1997)

The Third Round consisted of presenting expert panel members with the ranked list generated from Round Two. All participants were provided the opportunity to concur with the list in its present form or make necessary adjustments. Further input regarding the manpower efficiency estimate was not requested in Round Three due to reaching stability in the previous round. The complete questionnaire issued for this round is located in Appendix E. Once all responses were received, the same methods utilized in Round Two were implemented to produce a revised weighted list and examine consensus.

Phase 3: Report Ranked Aspects & Forecasted Efficiency

With each Delphi round complete and respective inputs analyzed, the study progressed to Phase Three. Within this phase, the final list of aspects is determined and the final forecasted manpower efficiency revealed. Ultimately, Phase Three reports the results of the Delphi study. The outcomes of Phase Three to include each round of this Delphi study are presented in the Results section of this article.

Results

Establishing the Manpower Baseline

Table 6 presents results for the monthly man-hours per UTC estimates generated through simulation; in addition, Table 6 reports the total man-hours required annually to accomplish the managing, reporting, handling, and maintaining of CE equipment UTCs in a dispersed posture.

Table 6. CE Equipment UTC Manpower Baseline

		Monthly Man-Hours per UTC		Total Annual Man-Hours	
UTC	**# CONUS Postured by Active Duty**	**Median***	**Mean#**	**Median**	**Mean**
4F9EE	10	17	18	2078	2204
4F9EF	25	85	91	25511	27225
4F9EH	11	24	26	3142	3393
4F9ET	21	169	183	42568	46224
4F9FE	6	15	15	1100	1084
4F9FF	8	12	12	1139	1113
4F9FJ	20	10	10	2359	2506
4F9FX	3	40	44	1437	1598
4F9WL	10	75	83	9014	9967
4F9WN	14	39	44	6601	7319
4F9WP	15	33	36	6010	6509
4F9WS	9	31	33	3304	3576
4F9X1	54	58	60	37664	38975
4F9X3	40	89	92	42588	44256
4F9X6	27	42	44	13576	14307
4F9X7	13	49	51	7641	7898
		Totals		205732	218155

* - Estimates derived using a median sample value to construct simulated triangular distributions
# - Estimates derived using a mean sample value to construct simulated triangular distributions

Examining Table 6, the study finds the total annual man-hours to be 205,732 or 218,155 when using either the median or mean sample values to develop triangular distributions for simulation; the annual totals produce a percent difference of 5.86%. The relatively small percent difference indicates the monthly man-hours per UTC estimates derived through simulation varied only slightly between the two different triangular distributions constructed. The annual man-hours estimate generated from the mean sample values was used as the final manpower baseline. This was done because the mean better represents skewed distributions as a measure of central tendency, thus the triangular distributions developed using this value more closely represent the sample data collected from the CE community (McClave, Benson, and Sincich, 2011).

Further quantifying the number and cost of personnel required to fulfill the estimated manpower baseline, this study assumed an individual to contribute 1,760 hours in a given year and the typical troop conducting CE equipment UTC duties to be an E-5 with an annual DoD composite pay rate of $79,953 (DoD, 2013). Accordingly, the manpower required to effectively complete all tasks associated with CE equipment UTCs in the currently dispersed posture requires 124 personnel at a cost of $9.9 million. The figures represent a substantial level of effort being undertaken to upkeep contingency equipment even though personnel are not allocated for such duties. Consequently, the CE community is taking $9.9 million in labor costs “out of hide”, detracting from the primary functions required to operate and maintain USAF airbases.

Identifying Aspects and Forecasting Efficiency

<u>Round One</u>

The Round One questionnaire was disseminated to 14 experts who were identified using criteria previously discussed; 12 of the panel members responded resulting in a response rate of 85.7%. All 12 initial respondents participated for the duration of the study. Utilizing responses to the background questions posed by Round One, the study discerned expert panel members cumulatively maintained over 250 years of experience within the USAF CE functional community, with over 60% of that experience contributing directly or indirectly to the managing, reporting, handling, and maintaining of CE equipment UTCs. In addition, experts represented perspectives from both the operational and tactical level of execution with a split of 58% and 42%, respectively. The background question results indicate the personnel selected to provide input for the Delphi study held sufficient experience and breadth of perspective to successfully address the latter two research objectives. Examining the research questions posed in the same round, the experts illuminated 12 aspects pertaining to either consolidation or assignment of dedicated personnel that would contributed to manpower efficiency over the current state. Table 7 details each identified aspect and the component to which they fall under. As mentioned beforehand, the accuracy of compiling all aspects was validated through confirmation with the expert panel. As for the manpower efficiency estimate requested of each panel member, Round One results revealed a median value of 60% with an IQR of 40-73%.

Table 7. Aspects Contributing to Manpower Efficiency

Consolidation Aspects	Assignment of Dedicated Personnel Aspects
Asset visibility	Personnel oversight
Pooling personnel/functions	Personnel training/proficiency
Logistics operations	Personnel availability
Warehouse configuration	Positional continuity
Asset procurement	Equipment familiarity/interaction
Single, standardized process	Standardized, repetitive task

Round Two

Progressing to Round Two, experts ranked the aspects under each component based on what they perceived was most critical for management to focus on successfully implementing so that the expected manpower efficiency would be realized. The resulting ranks distilled from all 12 expert respondents are captured in Table 8. In addition, Table 8 also depicts the corresponding Kendall's *W* achieved for each ranked list through Round Two. Referencing Schmidt's (1997) interpretation shown in Table 5, the consolidation and assignment of dedicated personnel ranked lists resulted in relatively weak agreement. Consequently, a third round was conducted to provide controlled feedback and allow participants the opportunity to revise their rankings with the anticipation a higher level of consensus would be realized. Beyond the ranked lists, experts were permitted to amend their initial manpower efficiency estimate based on the compiled list of aspects presented and information detailing the median value reported in Round One. The revised estimates resulted in a repeated median value of 60% and an IQR of 50-63.7%. The reported values suggest the expert panel member estimates reached stability, thus further questions with regards to forecasting manpower efficiency were not pursued. Accordingly, this study utilizes the median value of 60% as the expected manpower efficiency over the current state should the identified aspects be properly implemented in the future CE equipment UTC posture. The forecasted value largely coincides with the efficiency reported in the Security Forces study previously discussed, where current and future states mirror those proposed by the AFCEC (Skipper et al, 2010; AFCEC, 2012). Furthermore, the processes and tasks required of each functional community are similar in nature, further explaining the comparable results.

Table 8. Consolidation and Assignment of Dedicated Personnel Aspect Rankings

Ranking	Consolidation Aspects ($W = 0.46$)	Ranking	Assignment of Dedicated Personnel Aspects ($W = 0.29$)
1	Single, Standardized Process	1	Positional Continuity
2	Asset Visibility	2	Standardized, Repetitive Task
3	Pooling Personnel/Functions	3	Personnel Training/Proficiency
4	Asset Procurement	4	Equipment Familiarity/Interaction
5	Logistics Operations	5	Personnel Availability
6	Warehouse Configuration	6	Personnel Oversight

Round 3

Round Three provided each expert the ranked lists generated through Round Two. Experts were afforded the opportunity to review the rankings and adjust each aspect's relative standing as needed. The Round Three rankings coincided exactly with those reported in Round Two; however, Round Three produced a high level of agreement for both component lists. For instance, the ranked list corresponding with aspects of consolidation that contribute to manpower efficiency produced a Kendall's W of 1.00. Likewise, the ranked list corresponding with aspects of assigning dedicated personnel that contribute to manpower efficiency produced a Kendall's W of 0.90. As a result, no further rounds of questioning were required.

Summarizing and Integrating Results

The CE community is expending significant resources to manage, report, handle, and maintain equipment UTCs in the currently dispersed posture as revealed by Objective One of this study. Fortunately, through consolidation and assignment of dedicated personnel, a substantial number of those resources can be redirected toward executing primary functions. By coupling the forecasted efficiency of 60% with the manpower baseline of 124 man-years, it is expected the future state of equipment UTCs would annually require 50 personnel with an associated labor cost of $4.0 million. Accordingly, the CE community would recapture over $5.9 million (74 personnel) each year for the execution of primary functions to maintain and operate CONUS airbases. While not reducing the bottom line, this study categorizes the redirected labor as savings due to the funds presently being "lost" to unaccounted duties.

Beyond manpower requirements, the aspects illuminated and ranked by this study offer the CE community insight on where to place their focus to ensure operating efficiency and its subsequent savings are realized. For instance, in regards to assignment of dedicated personnel, managers must pay particular attention to positional continuity. This could be done by enforcing extended periods of personnel assignment or developing a robust continuity program to better transition during turnover. As for consolidation, managers must implement a single, standardized process which could be realized through various process mapping techniques. Of course, these methods are only examples as the intent of this study is not to develop a roadmap for the CE community. Instead, the intent of this study is to offer preliminary insight into where such a road might lead and what infrastructure must be in place to navigate it successfully; manpower savings being the end of the road and aspects of consolidation and assignment of dedicated personnel being the infrastructure required to get there.

Conclusion

The military case presented certainly indicates a forward, central inventory holding posture is beneficial when compared to a dispersed posture. For instance, consolidation of CE equipment UTCs mitigates the handling, tracking, and capability discrepancies identified by the AFCEC. Furthermore, consolidation results in significant operational efficiencies, aligning with USAF strategic goals that call for ways to offset funding impacts of the BCA of 2011. Perhaps most importantly, as revealed through this study, coupling consolidation with the assignment of dedicated personnel leads to quantifiable estimates of increased manpower efficiency and subsequent savings. Essentially, the CE community is provided with more than $5.9 million, or 74 personnel, redirected toward executing primary duties required to operate and maintain CONUS airbases. As a result, this study recommends the CE community pursue a consolidated inventory holding posture.

Unfortunately, the level of analysis achieved through this study only indicates that a consolidated structure should be pursued. It does not delineate between either a single- or dual-location configuration. It is recommended a formal manpower study be conducted to better discern differences in personnel requirements between the two alternative options. In addition, such a study should capture inputs from the ARC (Air Reserve Component) as only active duty implications are considered here due to data availability. Future research should also be conducted in the areas of initial implementation cost, facility life cycle cost, and risk associated with the different posturing structures to provided comprehensive analysis pertaining to the CE community decision. Investigating such information allows senior leaders to examine all aspects of the problem at hand, ultimately leading to an informed, objective solution. Lastly, the military case presented has implications for other functional areas within the DoD which maintain a dispersed posture and are considering consolidation of critical inventories.

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Appendix A

Manpower Baseline Data Collection Tool

***4. How many 4F9ED UTCs does your unit maintain?**

	1	2	3	4	5	6
# of 4F9ED UTCs	○	○	○	○	○	○

***5. Does your unit utilize BITS to manage the 4F9ED UTC?**

○ Yes

○ No

***6. Please provide the number of man-hours contributed toward REPORTING for the 4F9ED UTC.**

SORTS

ARTs

DRRS

Team Size

***7. Please provide the number of man-hours contributed toward INVENTORY for the 4F9ED UTC.**

Annual Full Inventory

Before & After Deployment

Before & After Training Exercise

Before & After Op Readiness Exercise

Validation & Reporting

Team Size

***8. Please provide the number of man-hours contributed toward MAINTENANCE for the 4F9ED UTC.**

Annual Full Inventory

Before & After Deployment

Before & After Training Exercise

Before & After Op Readiness Exercise

Validation & Reporting

Team Size

***9. Please provide the number of man-hours contributed toward REPLACING SUPPLIES for the 4F9ED UTC.**

Annual Full Inventory

Before & After Deployment

Before & After Training Exercise

Before & After Op Readiness Exercise

Validation & Reporting

Team Size

***10. Please provide the number of man-hours contributed toward HAZARDOUS MATERIAL HANDLING and DISPOSAL for the 4F9ED UTC.**

Annual Full Inventory

Before & After Deployment

Before & After Training Exercise

Before & After Op Readiness Exercise

Validation & Reporting

Team Size

Appendix B

Delphi Study Phase Two, Round One
CE Equipment UTC Consolidation Questionnaire

Thank you for agreeing to participate in this Delphi Study. The purpose of this study is to perform research concerning the consolidation of civil engineer (CE) equipment Unity Type Codes (UTCs) and resulting manpower implications. The objective is to determine whether the consolidation of CE equipment UTCs and the assignment of dedicated personnel whose primary and only responsibility is the managing, reporting, handling, and maintaining of said UTCs can reasonably result in manpower efficiencies. The sponsor for this research is Lt Col George Petty, AFCEC/CXX.

Please note the following:
Benefits and Risks: There are no personal benefits or risks for participating in this study. Your participation in completing this questionnaire should take 30-45 minutes per round.

Confidentiality: Your responses are completely confidential, and your identity will remain anonymous. No individual data will be reported; only data in aggregate will be made public. Data will be kept in a secure, locked cabinet to which only the researchers will have access. If you have any questions or concerns about your participation in this study, please contact

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Voluntary Consent: Your participation is completely voluntary. You have the right to decline to answer any question, to refuse to participate, or to withdraw at any time. Your decision of whether or not to participate will not result in any penalty or loss of benefits to which you are otherwise entitled. Completion of the questionnaire implies your consent to participate.

Background:

In October of 2012, the Air Force Civil Engineer Center (AFCEC) released a study concerning the current posture of equipment UTCs maintained by the CE community. The results cite inconsistencies in handling, tracking, and capability reporting due to the geographical separation of equipment; in addition, the study documents system redundancies that create unneeded waste (AFCEC, 2012). Furthermore, the dispersed posture requires several points of contact to transfer UTCs within the CONUS prior to overseas shipment; the excess handling, coordination, and movement creates a slow, burdensome deployment process that drives up cost and enables delay (Overstreet, 2004).

As a result of the current system inadequacies, the CE community began to review alternative options for equipment UTC positioning within the CONUS. The investigation included several military studies suggesting the consolidation and forward placement of inventories results in cost savings and substantial efficiencies over a dispersed posture (Overstreet, 2004; Skipper, Bell, Cunningham, and Mattioda, 2010). Due to these findings, the AFCEC proposed three courses of action (COAs) for further analysis:

1. Maintain current dispersed posture
2. Establish one CONUS holding location near a Port of Embarkation (POE)
3. Establish two CONUS holding locations, one on the west and east coast near a POE

Given the inherent problem complexity, AFCEC requested Air Force Institute of Technology (AFIT) assistance to analyze the proposed alternative options. Specifically, the investigation is analyzing: initial implementation cost, risk exposure, and expected manpower efficiency. The purpose of this portion of the research is to elicit from subject matter experts aspects of consolidating equipment UTCs and assigning dedicated personnel to manage, report, handle, and maintain said UTCs that result in potential manpower efficiencies. It also seeks to quantify the most reasonable expectation of manpower efficiency that can be realized through consolidation and assignment of dedicated personnel.

By responding, you have the opportunity to vector strategic decisions concerning the future posture of CE equipment UTCs. Your input will inform conclusions on whether consolidating equipment UTCs and assigning dedicated personnel to manage, report, handle, and maintain said UTCs will result in manpower efficiency. Thank you for participating in this study and helping apply your experience and knowledge to shape decision-making outcomes by our senior leaders. We appreciate your time and candid responses.

Process:

1. Please complete this questionnaire **electronically** and return it to: **scott.adamson@afit.edu** no later than **20 December 2013**. If you have questions, I can be reached at that email or at DSN: 317-785-3636 ext. 7557.

2. This questionnaire is an instrument of a Delphi study. The Delphi method is an iterative, group communication process which is used to collect and distill judgments of experts using a series of questionnaires interspersed with feedback. The questionnaires are designed to focus on problem, opportunities, solutions, or forecasts. Each questionnaire is developed based on results of the previous questionnaire. The process continues until the research is answered. For example, when consensus is reached, sufficient information has been exchanged. This usually takes, on average, 3-4 rounds.

3. There are six primary questions for this round. The questionnaire is non-attribution, so **please elaborate fully on your answers** and feel free to provide additional insight, if you deem it relevant, even if it is not specifically requested by the questions. Once all questionnaire responses are received and analyzed, you will be asked to review and revise you initial responses based on responses provided by the entire group. Subsequent rounds will be announced as needed and all research is scheduled to conclude by 6 February 2014.

Questions:
Background Questions:

1. How many years of experience do you have in the USAF CE functional community?

2. How many years of experience do you have that directly or indirectly contribute to managing, reporting, handling, and maintaining CE equipment UTCs at either the tactical or operational level?

3. What is your current duty position?

Research Questions:

Please answer the following questions as clearly and concisely as possible without omitting critical information or rationale required for the group to consider your expert judgment. Base your responses on your own personal experience, knowledge, and perceptions.

1. What aspects, if any, of consolidating CE equipment UTCs to one or two locations do you perceive would contribute to manpower efficiency* in managing, reporting, handling, and maintaining said UTCs over the current system in place (*e.g.* increased inventory visibility, single standardized process, better warehouse management)?

2. What aspects, if any, of assigning dedicated personnel whose primary and only responsibility is managing, reporting, handling, and maintaining CE equipment UTCs do you perceive would contribute to manpower efficiency* in said duties over the current system in place (*e.g.* increased continuity, more equipment familiarity/interaction, better trained personnel)?

3. Considering all aspects you identified in Questions 1 and 2, what percent manpower efficiency* change (improvement or decline) would you expect in the consolidation of equipment UTCs to one or two location with the assignment of dedicated personnel?

**Manpower efficiency is defined as the lesser amount of time required for assigned, dedicated personnel at a consolidated location to complete the same tasks required of base personnel in managing, reporting, handling, and maintaining CE equipment UTCs.*

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Appendix C

Consolidation and Assignment of Dedicated Personnel Aspects Identified by Expert Panel

Consolidation Aspects	
1	Asset visibility
2	Pooling personnel/functions
3	Logistics operations
4	Warehouse configuration
5	Asset procurement
6	Single, standardized process

<u>CONSOLIDATION ASPECTS</u>

1. Asset visibility – Through your or other expert opinion it was discerned consolidation offers enhanced asset visibility and accountability which holds the potential for increased manpower efficiency. Expressed reasoning indicates consolidation reduces coordination efforts among several geographically dispersed units when determining what equipment UTCs are ready to deploy and where they are located. In addition, the resulting enhanced asset visibility allows personnel to identify which equipment UTCs require attention, thus reducing man-hours by eliminating the potential for redundant work and facilitating efficient execution of managing, handling, reporting, and maintaining duties. Lastly, consolidation provides less complex communication channels to other organizations requesting or disseminating relevant information.

2. Pooling personnel and functions – Through your or other expert opinion it was discerned consolidation offers enhanced pooling of personnel and functions which holds the potential for increased manpower efficiency. Expressed reasoning indicates consolidation facilitates personnel to be trained on the managing, reporting, handling, and maintaining of several different equipment UTCs rather than a single type associated with a particular AFS. As a result, manpower can be directed to fill demand where required offering a more flexible, efficient workforce. In addition, with functions or duties being executed at the same location it reduces the personnel overhead required to complete such tasks. For example, the current state requires all units to execute monthly reporting on equipment. This would now be done through a single report, thus requiring fewer personnel to complete the task.

3. Logistics operations – Through your or other expert opinion it was discerned consolidation offers enhanced logistical operations and coordination which holds the potential for increased manpower efficiency. Expressed reasoning indicates consolidation reduces the logistics tail; for instance, airlift or sealift can be synced directly with the consolidated locations rather than transferring assets from multiple different units prior to overseas deployment. As a result, less man-hours are required to coordinate and move assets for contingency taskings.

4. Warehouse configuration - Through your or other expert opinion it was discerned consolidation offers enhanced warehouse configuration which holds the potential for increased manpower efficiency. Expressed reasoning indicates consolidation facilitates proper allocation of storage space and warehouse equipment. Designing optimal storage/work areas allows personnel to streamline processes and more quickly accomplish duties associated with managing, reporting, handling, and maintaining equipment UTCs. Furthermore, retaining appropriate equipment (*e.g.* forklifts) assists in completing said duties in a timely manner without unnecessary hardship.

5. Asset procurement – Through your or other expert opinion it was discerned consolidation offers enhanced asset procurement which holds the potential for increased manpower efficiency. Expressed reasoning indicates consolidation allows for the effective implementation of just-in-time (JIT) purchases for reduced shelf life items. JIT purchases eliminate redundant and unnecessary man-hours presently expended managing said items. Furthermore, consolidation combines funding requirements of dispersed units and enables strategic sourcing. Such practices executed at one or two locations substantially reduce the man-hours required to procure items by joining multiple smaller purchases into a single bulk purchase.

6. Single, standardized process – Through your or other expert opinion it was discerned consolidation offers implementation of a single, standardized process which holds the potential for increased manpower efficiency. Expressed reasoning indicates a single, standardized process increases throughput and consistency allowing tasks to be completed in a shorter timeframe. Additionally, it provides for the complete implementation of the Barcode Inventory Tracking System (BITS) or other automated inventory systems allowing personnel to more quickly execute duties associated with the managing, reporting, handling, and maintaining of equipment UTCs.

Assignment of Dedicated Personnel Aspects	
1	Personnel oversight
2	Personnel training/proficiency
3	Personnel availability
4	Positional continuity
5	Equipment familiarity/interaction
6	Standardized, repetitive task

<u>ASSIGNMENT OF DEDICATED PERSONNEL ASPECTS</u>

1. Personnel oversight – Through your or other expert opinion it was discerned assignment of dedicated personnel offers enhanced personnel oversight which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel allows for individuals to focus solely on executing duties associated with the managing, reporting, handling, and maintaining of equipment UTCs. Accordingly, managers will have the ability to better validate and verify proper duty execution

resulting in the job being done right the first time. As a result, less man-hours are expended fixing or accomplishing redundant work.

2. Personnel training and proficiency – Through your or other expert opinion it was discerned assignment of dedicated personnel offers enhanced personnel training and proficiency which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel facilitates the execution of central training programs and progress monitoring to ensure individuals possess and maintain the knowledge and ability to fully execute associated equipment UTC duties, thus mitigating skill set mismatch and mismanagement. As a result, less man-hours are expended continually walking new personnel through the learning process. In addition, the high level of training facilitates increased throughput when executing assigned tasks.

3. Personnel availability – Through your or other expert opinion it was discerned assignment of dedicated personnel offers increased personnel availability which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel ensures individuals are available when tasks require accomplishment. Such availability mitigates the need to piecemeal together tasks due to competing primary duties resulting in quicker execution and the ability to pool personnel where needed.

4. Positional continuity – Through your or other expert opinion it was discerned assignment of dedicated personnel offers increased positional continuity which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel reduces the frequency of turnover in positions required for the managing, reporting, handling, and maintaining of equipment UTCs. Accordingly, requisite knowledge and abilities for accomplishing said duties are steadily maintained resulting in a higher level of performance than can be gained by the current state. As a result, the assigned workforce becomes more effective and efficient.

5. Equipment familiarity and interaction – Through your or other expert opinion it was discerned assignment of dedicated personnel offers increased equipment familiarity and interaction which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel facilitates daily handling of equipment UTCs due to it being the primary duty. As a result, re-learning is substantially reduced and tasks can be accomplished in a more efficient manner.

6. Standardized, repetitive tasks – Through your or other expert opinion it was discerned assignment of dedicated personnel offers the execution of standardized, repetitive tasks which holds the potential for increased manpower efficiency. Expressed reasoning indicates assigning dedicated personnel facilitates the implementation of standardization across all equipment UTC aspects to include packaging, inspection, maintenance, and deployment processes. As a result, the tasks become repetitive for all personnel promoting quicker execution and higher throughput. In addition, it mitigates the need for continual re-learning.

Appendix D

Delphi Study Phase Two, Round Two
CE Equipment UTC Consolidation Questionnaire

Thank you for agreeing to participate in this Delphi Study. The purpose of this study is to perform research concerning the consolidation of civil engineer (CE) equipment Unity Type Codes (UTCs) and resulting manpower implications. The objective is to determine whether the consolidation of CE equipment UTCs and the assignment of dedicated personnel whose primary and only responsibility is the managing, reporting, handling, and maintaining of said UTCs can feasibly result in manpower efficiencies. The sponsor for this research is Lt Col George Petty, AFCEC/CXX.

Please note the following:

Benefits and Risks: There are no personal benefits or risks for participating in this study. Your participation in completing this questionnaire should take ~15 minutes per round.

Confidentiality: Your responses are completely confidential, and your identity will remain anonymous. No individual data will be reported; only data in aggregate will be made public. Data will be kept in a secure, locked cabinet to which only the researchers will have access. If you have any questions or concerns about your participation in this study, please contact

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Voluntary Consent: Your participation is completely voluntary. You have the right to decline to answer any question, to refuse to participate, or to withdraw at any time. Your decision of whether or not to participate will not result in any penalty or loss of benefits to which you are otherwise entitled. Completion of the questionnaire implies your consent to participate.

Background:

Your responses to the first round questionnaire identified both consolidation and assignment of dedicated personnel aspects that potentially contribute to manpower efficiency over the current state. Overall twelve aspects were identified with six being attributed to each component. In addition, the median value for all manpower efficiency estimates, gained by implementing both consolidation and assignment of dedicated personnel, was 60%. With this information, the second questionnaire will determine, from a management perspective, which of the identified aspects are most critical to ensuring successful realization of the forecasted manpower efficiency, and thus require more attention from managers and supervisors. In addition, respondents are offered an opportunity to revise initial manpower efficiency estimates based on the compiled expert panel member responses.

Process:

1. Please complete this questionnaire **electronically** and return it to: **scott.adamson@afit.edu** no later than **22 January 2013**. If you have questions, I can be reached at that email or at DSN: 317-785-3636 ext. 7557.

2. This questionnaire is an instrument of a Delphi study. The Delphi method is an iterative, group communication process which is used to collect and distill judgments of experts using a series of questionnaires interspersed with feedback. The questionnaires are designed to focus on problem, opportunities, solutions, or forecasts. Each questionnaire is developed based on results of the previous questionnaire. The process continues until the research is answered. For example, when consensus is reached, sufficient information has been exchanged. This usually takes, on average, 3-4 rounds.

3. This follow-up questionnaire represents the second round of this study. Once all responses are received and analyzed, you may be asked to review and revise your initial responses based on those provided by the entire group. The questionnaire is non-attribution, so **please elaborate fully on any qualitative comments you feel are necessary** and feel free to provide additional insight, if you deem it relevant, even if it is not specifically requested by the questions. Subsequent rounds will be announced as needed and all research is scheduled to conclude by 6 February 2014.

Questions:

Please rank order the responses given to the selected round one questions based on which aspects you perceive as most critical for management to focus on successfully implementing so that the expected manpower efficiency is realized:

1. Original Question: What aspects, if any, of consolidating CE equipment UTCs to one or two locations do you perceive would contribute to manpower efficiency* in managing, reporting, handling, and maintaining said UTCs over the current system in place (*e.g.* increased inventory visibility, single standardized process, better warehouse management)?

Respondents' Answers	Rank (1-6, 1 being most important)	Comments
Single, Standardized Process		
Pooling Personnel/Functions		
Warehouse Configuration		
Asset Visibility		
Asset Procurement		
Logistics Operations		

2. Original Question: What aspects, if any, of assigning dedicated personnel whose primary and only responsibility is managing, reporting, handling, and maintaining CE equipment UTCs do you perceive would contribute to manpower efficiency* in said duties over the current system in place (*e.g.* increased continuity, more equipment familiarity/interaction, better trained personnel)?

Respondents' Answers	Rank (1-6, 1 being most important)	Comments
Positional Continuity		
Equipment Familiarity/Interaction		
Standardized, Repetitive Task		
Personnel Oversight		
Personnel Training/Proficiency		
Personnel Availability		

Provided the compiled list of aspects identified by you or other expert personnel, do you wish to revise your initial estimate? If so, please provide your revised estimate below. The median value for all first round estimates is listed for your reference.

3. Original Question: Considering all aspects you identified in Questions 1 and 2, what percent manpower efficiency* change (improvement or decline) would you expect in the consolidation of equipment UTCs to one or two location with the assignment of dedicated personnel?

    Median: 60% manpower efficiency improvement

Appendix E

Delphi Study Phase Two, Round Three
CE Equipment UTC Consolidation Questionnaire

Thank you for agreeing to participate in this Delphi Study. The purpose of this study is to perform research concerning the consolidation of civil engineer (CE) equipment Unity Type Codes (UTCs) and resulting manpower implications. The objective is to determine whether the consolidation of CE equipment UTCs and the assignment of dedicated personnel whose primary and only responsibility is the managing, reporting, handling, and maintaining of said UTCs can feasibly result in manpower efficiencies. The sponsor for this research is Lt Col George Petty, AFCEC/CXX.

Please note the following:
Benefits and Risks: There are no personal benefits or risks for participating in this study. Your participation in completing this questionnaire should take ~15 minutes per round.

Confidentiality: Your responses are completely confidential, and your identity will remain anonymous. No individual data will be reported; only data in aggregate will be made public. Data will be kept in a secure, locked cabinet to which only the researchers will have access. If you have any questions or concerns about your participation in this study, please contact

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Voluntary Consent: Your participation is completely voluntary. You have the right to decline to answer any question, to refuse to participate, or to withdraw at any time. Your decision of whether or not to participate will not result in any penalty or loss of benefits to which you are otherwise entitled. Completion of the questionnaire implies your consent to participate.

Background:

This is round three of the Delphi study. The purpose of this round is to review the rank order developed by the group in an effort to reach consensus. Please review the group-determined rank and indicate your agreement, or re-rank the list as you deem necessary. The items are ranked in order from most important to least important.

Process:

1. Please complete this questionnaire **electronically** and return it to: **scott.adamson@afit.edu** no later than **29 January 2013**. If you have questions, I can be reached at that email or at DSN: 317-785-3636 ext. 7557.

2. This questionnaire is an instrument of a Delphi study. The Delphi method is an iterative, group communication process which is used to collect and distill judgments of experts using a series of questionnaires interspersed with feedback. The questionnaires are designed to focus on problem, opportunities, solutions, or forecasts. Each questionnaire is developed based on results of the previous questionnaire. The process continues until the research is answered. For example, when consensus is reached, sufficient information has been exchanged. This usually takes, on average, 3-4 rounds.

3. This follow-up questionnaire represents the third round of this study. Once all responses are received and analyzed, you may be asked to review and revise your initial responses based on those provided by the entire group. The questionnaire is non-attribution, so **please elaborate fully on any qualitative comments you feel are necessary** and feel free to provide additional insight, if you deem it relevant, even if it is not specifically requested by the questions. Subsequent rounds will be announced as needed and all research is scheduled to conclude by 6 February 2014.

Questions:

Please review the group-determined ranking for each question. Indicate your agreement by selecting yes, or select no and re-rank as needed:

1. Original Question: What aspects, if any, of consolidating CE equipment UTCs to one or two locations do you perceive would contribute to manpower efficiency* in managing, reporting, handling, and maintaining said UTCs over the current system in place (*e.g.* increased inventory visibility, single standardized process, better warehouse management)?

I agree with the rankings as listed: ____ Yes / ____ No

Group Determined Rank	Rank (1-6, 1 being most important)	Comments
Single, Standardized Process **(1)**		
Asset Visibility **(2)**		
Pooling Personnel/Functions **(3)**		
Asset Procurement **(4)**		
Logistics Operations **(5)**		
Warehouse Configuration **(6)**		

2. Original Question: What aspects, if any, of assigning dedicated personnel whose primary and only responsibility is managing, reporting, handling, and maintaining CE equipment UTCs do you perceive would contribute to manpower efficiency* in said duties over the current system in place (*e.g.* increased continuity, more equipment familiarity/interaction, better trained personnel)?

I agree with the rankings as listed: ____ Yes / ____ No

Group Determined Rank	Rank (1-6, 1 being most important)	Comments
Positional Continuity **(1)**		
Standardized, Repetitive Task **(2)**		
Personnel Training/Proficiency **(3)**		
Equipment Familiarity/Interaction **(4)**		
Personnel Availability **(5)**		
Personnel Oversight **(6)**		

Appendix F

IRB Exemption Approval

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OHIO

11 December 2013

MEMORANDUM FOR LT COL TAY W. JOHANNES

FROM: Joseph B. Skipper, Lt Col, Ph.D.
AFIT IRB Research Reviewer
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for "Strategic Positioning of United States Air Force Civil Engineer Contingency Equipment within the Supply Chain."

1. Your request was based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

2. Your study qualifies for this exemption because you are not collecting sensitive data, which could reasonably damage the subjects' financial standing, employability, or reputation. Further, the demographic data you are collecting cannot realistically be expected to map a given response to a specific subject. Your plan includes ample and appropriate measures to safeguard any information collected and your mitigation plan should such breech occur is adequate.

3. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with this office immediately.

JOSEPH B. SKIPPER, Lt Col, Ph.D.
AFIT Research Reviewer

V. Conclusion

This chapter summarizes the findings presented and discussed in each of the three scholarly articles. While each article contains its own conclusions and recommendations, this chapter integrates those subjects with respect to the overall research questions and further discusses the significance of the research as it applies to the civil engineer (CE) community and the United States Air Force (USAF). Finally, proposals for future research close this thesis effort.

Review & Integration of Findings

This research endeavor followed a phased approach, with each phase discerning key decision criteria required to objectively answer the following overall research questions posed by the potential consolidation of CE contingency equipment:

1. How and where should contingency equipment be postured if consolidated?
2. What is the expected manpower required to operate and sustain a consolidated posture?
3. What are the expected savings resulting from consolidation?

The succeeding paragraphs identify the findings of each phase and integrate their contribution to the research effort.

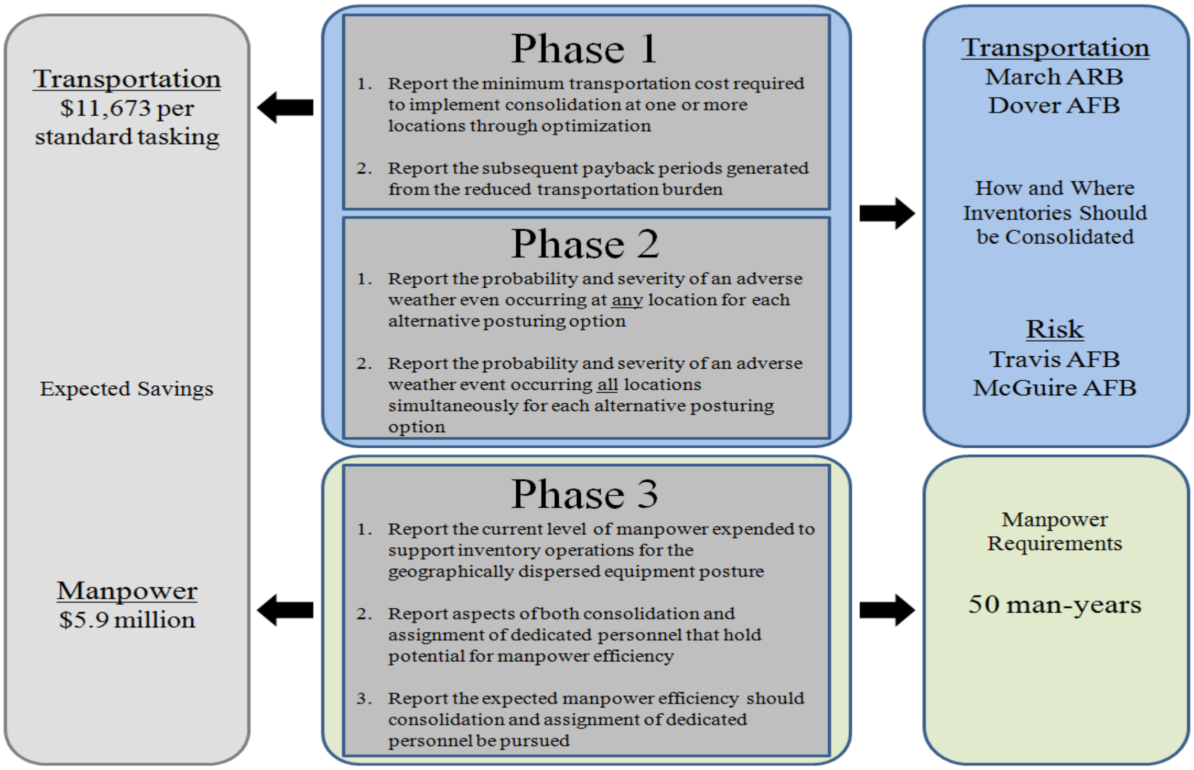
Phase One, presented within the first scholarly article, examined and determined initial transportation costs required to consolidate CE equipment Unit Type Codes (UTCs) to any combination of the proposed candidate sites. The analysis identified both the least cost option and savings realized by the reduced transportation burden. Recommendations consisted of pursuing a dual-location configuration with March Air Reserve Base (ARB) and Dover Air Force Base (AFB) as the selected sites. The initial cost to execute consolidation being $264,762, with expected transportation savings of $11,673 each time a standard tasking is deployed.

Phase Two, presented within the second scholarly article, investigated and assembled risk profiles for each candidate site to include its opposite coast pairing. The risk profiles were constructed based on the probability for a candidate site to experience supply disruptions due to the occurrence of an adverse weather event. The expected severity of each event occurrence was also considered. The analysis identified the inventory posture delivering the lowest possible disruption risk. Recommendations consisted of pursuing a dual-location configuration with McGuire AFB and Travis AFB as the selected sites. This pairing of east and west coast sites combines for less than one total day of complete disruption over a twenty year period.

Phase Three, presented within the third scholarly article, examined and determined manpower implications arising from the consolidation of CE contingency equipment. The analysis identified a manpower baseline required to support the status quo as well as the expected manpower efficiency realized through consolidation. In addition, several aspects pertaining to consolidation and assignment of dedicated personnel were identified, whose successful implementation is required to realize such efficiency. By combining Phase Three findings, the expected manpower requirements needed to support a consolidated posture consisted of 50 man-years. The reduced personnel burden redirects over $5.9 million (74 man-years) back to executing primary duties required to operate and maintain CONUS airbases.

With each phase discerning decision criteria that contribute to one or more of the overall research questions, integration of their findings is required to arrive at final conclusions and recommendations. Figure 2 illustrates how each phase's findings fit within the research approach and add to the overall thesis effort.

Figure 2. Integration of Research Findings



For Research Question One, both Phase One and Two facilitate deciding how and where inventories should be consolidated. Integrating both transportation cost and risk decision criteria, a dual-location configuration is recommended as both cost and risk components are minimized by employing such a posture. Noticeably, the recommended candidate sites do not coincide due to each phase identifying the base pairings which best meet their respective objectives. However, after examining cost and risk ratios between the two proposed pairings, Travis AFB and McGuire AFB exhibit less than half the risk exposure of March ARB and Dover AFB with less than a 5% increase in cost. Accordingly, this research recommends pursuing Travis AFB and McGuire AFB as the selected dual-location sites.

For Research Question Two, Phase Three was the sole contributor in determining manpower requirements. Appropriately, its findings were simply transferred over to arrive at the

50 personnel required to support a consolidated posture. For Research Question Three, both Phases One and Two identified savings realized through the consolidation of CE equipment UTCs. The manpower savings are reported as an annual figure with the CE community redirecting close to $6 million (74 man-years) in funds back to primary functions. The transportation savings are realized each time a standard equipment UTC tasking is deployed. Consequently, that figure will always be a factor of at least $11,673, but will vary each year as it is dependent on the current overseas operations tempo. At any rate, the CE community will achieve substantial savings by pursuing consolidation over the currently dispersed posture of contingency equipment.

Overall Conclusions, Recommendations & Research Significance

Supported by the findings distilled through each research phase as well as extant literature, this research recommends the CE community pursue consolidation of its equipment UTCs to two sites: one on the east and west coast near POEs. Specific site recommendations consist of Travis AFB and McGuire AFB. In addition, it is recommended the CE community allocate 50 personnel for support of the aforementioned consolidated posture to successfully maintain effective equipment operations. By employing consolidation, the CE community will experience increased operational efficiency and equipment readiness, better aligning itself with strategic objectives such as focused logistics. Furthermore, consolidation of CE equipment UTCs will realize transportation and manpower savings which are critical in present times of financial hardship and continual budget shortfalls.

This research highlights the significant benefits achieved through consolidation of critical inventories. Perhaps, most importantly, it identifies a viable avenue to realize substantial savings without sacrificing operational capability at a time when the DoD is hard pressed for funding.

Furthermore, it offers a blueprint that can be extended to other USAF functional areas considering alternatives to currently dispersed equipment sets. By following each phase and its respective methodology, other units can objectively discern whether or not consolidation is an executable option for their respective field.

Future Research

A multitude of opportunities present themselves for future research as a result of this thesis effort, several of which expand the scope or investigate limitations identified in Chapter One. First, the impact of consolidation on home station troop training is an area that requires further attention. While consolidation certainly enhances equipment readiness, reducing troop accessibility to equipment by locating it strictly to a couple locations may have unintended consequences—the reduced accessibility could lead to degraded states of troop readiness. Accordingly, further research is needed to identify and quantify such effects. Second, the scope of the study should be expanded to include CE equipment UTCs located in the United States Air Forces in Europe (USAFE) and Pacific Air Forces (PACAF). By doing so, a more realistic examination of risk can be conducted. As identified in Phase Two, the inclusion of overseas locations may reduce the risk threshold of a single-location to an acceptable level as defined by CE community senior leaders. Coupling such information with future research in the area of facility life cycle costs, it may be discerned that a single-location alternative is favored over the presently recommended dual-location configuration. Finally, as more data is collected over time and analysis techniques refined, each phase of research can be re-examined to validate or revise current recommendations, with the final intent of providing senior leaders a comprehensive review of all available information to facilitate objective decision-making.

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Vita

Captain Scott Adamson graduated in 2005 from Durant High School of Durant, Oklahoma. He commissioned as a second lieutenant in 2009 upon earning a Bachelor of Science degree in Civil Engineering from the United States Air Force Academy. After commissioning, Captain Adamson was assigned to the 354th Civil Engineer Squadron, Eielson AFB, Alaska, and served in base-level development programming, project management, and emergency management. From June 2011 to March 2012, Captain Adamson deployed to Afghanistan as an engineer and project manager on Provincial Reconstruction Team Laghman. He entered the Graduate School of Engineering and Management at the Air Force Institute of Technology in September 2012. Following graduation, he will be assigned to the 375th Civil Engineer Squadron, Scott AFB, Illinios.

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14. ABSTRACT The consolidation and forward positioning of critical inventories often provides substantial benefits over a geographically dispersed posture. Such benefits include, but are not limited to: increased inventory visibility, reduced transportation costs, and fewer manpower requirements. Presently, the United States Air Force (USAF) Civil Engineer (CE) community maintains a disseminated posture of equipment Unit Type Codes (UTCs), which regularly experiences inconsistencies in handling, tracking, and capability reporting. Provided the aforementioned discrepancies, this research effort examines several aspects surrounding the decision to potentially centralize critical CE inventories to either one or two locations. Specifically, the areas of cost, risk, and manpower are scrutinized to facilitate an objective decision by USAF CE senior leaders on whether or not to pursue an alternative equipment posture. Three scholarly articles are presented covering each area of interest and data supported recommendations are provided. The research offers insight concerning the decision of inventory consolidation as well as available methods to facilitate such a determination.						
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